NASA/CP—2000-210374

IN/19

Nineteenth International Microgravity Measurements Group Meeting

October 2000

The NASA STI Program Office . . . in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA Scientific and Technical Information (STI) Program Office plays a key part in helping NASA maintain this important role.

The NASA STI Program Office is operated by Langley Research Center, the Lead Center for NASA's scientific and technical information. The NASA STI Program Office provides access to the NASA STI Database, the largest collection of aeronautical and space science STI in the world. The Program Office is also NASA's institutional mechanism for disseminating the results of its research and development activities. These results are published by NASA in the NASA STI Report Series, which includes the following report types:

- TECHNICAL PUBLICATION. Reports of completed research or a major significant phase of research that present the results of NASA programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA's counterpart of peer-reviewed formal professional papers but has less stringent limitations on manuscript length and extent of graphic presentations.

- TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.

- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.

- CONFERENCE PUBLICATION. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or cosponsored by NASA.

- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.

- TECHNICAL TRANSLATION. English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services that complement the STI Program Office's diverse offerings include creating custom thesauri, building customized data bases, organizing and publishing research results . . . even providing videos.

For more information about the NASA STI Program Office, see the following:

- Access the NASA STI Program Home Page at ***http://www.sti.nasa.gov***

- E-mail your question via the Internet to help@sti.nasa.gov

- Fax your question to the NASA Access Help Desk at (301) 621-0134

- Telephone the NASA Access Help Desk at (301) 621-0390

- Write to:
  NASA Access Help Desk
  NASA Center for AeroSpace Information
  7121 Standard Drive
  Hanover, MD 21076

NASA/CP—2000-210374

Nineteenth International Microgravity Measurements Group Meeting

Proceedings of a conference sponsored by the Microgravity Science Division,
NASA Glenn Research Center
and held at the Sheraton Airport Hotel, Cleveland, Ohio
July 11–13, 2000

National Aeronautics and
Space Administration

Glenn Research Center

October 2000

Available from

NASA Center for Aerospace Information
7121 Standard Drive
Hanover, MD 21076
Price Code: A99

Available electronically at http://gltrs.grc.nasa.gov/GLTRS

Table of Contents

MGMG #19 Agenda

Tuesday, July 11, 2000

Paper #	start	end	Title	Presenter
	8:30 AM	8:45 AM	Welcoming remarks & logistics	Richard DeLombard / NASA GRC

Session A
ACCELEROMETER INSTRUMENT STATUS

Paper #	start	end	Title	Presenter
1	8:45 AM	9:15 AM	Space Acceleration Measurement Systems	William Foster / NASA GRC
2	9:15 AM	9:45 AM	Microgravity Acceleration Measurement System (MAMS) flight configuration verification and status	James Fox / Canopus Systems
	9:45 AM	10:00 AM	BREAK	
3	10:01 AM	10:30 AM	SAMS-FF: One system, many missions	Ron Sicker / NASA GRC & Dale Mortensen / ZIN Technologies
4	10:30 AM	11:15 AM	Microgravity measurement systems in JEM	Toshitami Ikeda / NASDA

Session B
SPECIAL TOPIC - MICROGRAVITY OUTREACH

Paper #	start	end	Title	Presenter
5	11:15 AM	11:45 AM	Microgravity outreach and education	Melissa Rogers / NCMR @ NASA GRC
	11:45 AM	1:15 PM	LUNCH	

Session C
SCIENCE IMPACTED BY DISTURBANCES IN MICROGRAVITY ENVIRONMENT

Paper #	start	end	Title	Presenter
6	1:15 PM	1:45 PM	Microgravity effects on microbiology in space laboratories	Emily Nelson / NASA GRC
7	1:45 PM	2:15 PM	On the evaluation of the overall disturbances induced by g-jitter on fluid physics experimentation in the ISS	Rudolfo Monti / Univ. of Naples, Italy
	2:15 PM	2:45 PM	BREAK	
8	2:45 PM	3:17 PM	Drag induced acceleration of the Shuttle measured with a fluid cell	Charles Ward / Univ. of Toronto, Canada
9	3:18 PM	3:50 PM	Effects of g-jitter on diffusion	Bjarni Tryggvason / CSA
10	3:50 PM	4:15 PM	Microgravity aspects of ACES: Atomic Clock Ensemble in Space	Walter E. Knabe / CNES/ESA

MGMG #19 Agenda

Wednesday, July 12, 2000

Paper #	start	end	Title	Presenter
			Session D	
			INTERNATIONAL SPACE STATION	
11	8:32 AM	9:06 AM	ISS microgravity environment Design Analysis Cycle 8	Steve DelBasso / Boeing Houston
12	9:07 AM	9:38 AM	Microgravity disturbance database - DAC-8	Otto Crenwelge / Dynacs
	9:38 AM	9:58 AM	BREAK	
13	9:58 AM	10:31 AM	ISS microgravity requirements and verification	Fred Henderson / TBE - Houston
14	10:32 AM	11:03 AM	The role of on-orbit stage-specific assessment of the ISS microgravity environment in meeting ISS Super Board requirements	Roy Christoffersen / SAIC Houston
15	11:04 AM	11:20 AM	ISS assembly sequence	Steve DelBasso / Boeing Houston
			TOUR OF SELECTED NASA GLENN FACILITIES	
16	11:21 AM	11:45 AM	Microgravity Emissions Laboratory facility and testing results	Thomas Goodnight / NASA GRC
	11:45 AM	12:00 PM	Tour orientation & instructions	Richard DeLombard / NASA GRC
	12:00 PM	1:30 PM	LUNCH	
	1:30 PM	2:00 PM	Meet buses at NASA Glenn parking lot	MGMG attendees
	2:00 PM	5:00 PM	Tour of Microgravity Emissions Laboratory, 2.2 Second Drop Tower, Fluid & Combusion Facility, and US Lab Mockup	MGMG attendees

MGMG #19 Agenda

Thursday, July 13, 2000

Paper #	start	end	Title	Presenter
			Session E VIBRATION ISOLATION	
17	8:31 AM	8:48 AM	g–LIMIT status briefing	Mark Whorton & Brad Perkins / NASA MSFC
18	8:48 AM	9:18 AM	Fundamentals of microgravity vibration isolation	Mark Whorton / NASA MSFC
19	9:18 AM	10:25 AM	The Active Rack Isolation System: program and technical status	Ian Fialho & Glenn Bushnell / Boeing
	10:25 AM	10:35 AM	BREAK	
20	10:36 AM	11:09 AM	Microgravity Vibration Isolation Mount (MIM) update and CSA plans for isolation systems on the ISS	Bjarni Tryggvason / CSA
			Session F GROUND TESTING	
21	11:11 AM	11:42 AM	US Lab microgravity tests: accelerations, transfer functions, comparisons with analyses	Otto Crenwelge / Dynacs
22	11:43 AM	12:00 PM	Testing the BUNDLE experiment for microgravity disturbance characterization	Janice Houston / Sverdrup, Huntsville
	12:00 PM	1:30 PM	LUNCH	
23	1:35 PM	1:56 PM	Proposed ground testing standard methods & techniques	Thomas Goodnight / NASA GRC
			Session G ENVIRONMENT ANALYSIS & VEHICLE CHARACTERIZATION	
24	1:58 PM	2:35 PM	In flight measurement results of microgravity space platform Photon #12 of September 1999 and plans on modified Photon-M #1 flight	Valentin Agarkov / CSDB, Samara, Russia
	2:35 PM	2:50 PM	BREAK	
25	2:50 PM	3:15 PM	PIMS real-time data reception and environment characterization	Ken Hrovat / ZIN Technologies
26	3:15 PM	4:00 PM	ISS Microgravity Environment Monitoring System (MEMS) - Part I: system design	Kenol Jules / NASA GRC
27	4:00 PM	4:20 PM	A method of simulation of microacceleration field from vibration source in microgravitational space platform	Valentin Agarkov / CSDB, Samara, Russia
			MEETING SUMMARY	
	4:20 PM	4:30 PM	Summary discussion of MGMG #19 and plans for MGMG #20	Richard DeLombard / NASA GRC

Microgravity Measurements Group Meeting #19

Summary

The Microgravity Measurements Group (MGMG) meetings have been held since 1988 to provide a forum for an exchange of information and ideas about various aspects of microgravity acceleration research in international microgravity research programs. These meetings are sponsored by the PI Microgravity Services (PIMS) project at the NASA Glenn Research Center for the NASA Microgravity Research Program and cooperating international microgravity research programs.

The nineteenth MGMG meeting was held 11-13 July 2000 at the Sheraton Airport Hotel in Cleveland, Ohio. The forty-four attendees represented NASA, other space agencies, universities, and commercial companies; eight of the attendees were international representatives from Japan, Italy, Canada, Russia, and Germany. Twenty-seven presentations were made on a variety of microgravity environment topics including the International Space Station (ISS), acceleration measurement and analysis results, science effects from microgravity accelerations, vibration isolation, free flyer satellites, ground testing, vehicle characterization, and microgravity outreach and education. A description of a tour of three microgravity-related facilities is also included in the minutes.

The meeting agenda is in the minutes and it lists each speaker, the title of their presentation, and the actual time of their presentation. The minutes also include the charts for each presentation which indicate the authors' name(s) and affiliation. In some cases, a separate written report was submitted and has been included here. The presentation charts are organized in order of their presentation at MGMG #19.

Mr. Valentin Argakov announced that his office in Samara, Russia had hosted a European microgravity symposium. In future years, this meeting will be opened to researchers in other countries. Mr. Agarkov invited MGMG attendees to consider submitting a paper for consideration at this conference.

GRC Facility Tour

A feature of the meeting was a tour of three facilities of NASA Glenn Research Center, the 2.2 Second Drop Tower, the Microgravity Emissions Laboratory, and the Fluids and Combustion Facility engineering models. This tour was arranged so that the MGMG #19 attendees could become more familiar with these microgravity facilities.

2.2 Second Drop Tower

This facility allows investigators to test experimental packages in a microgravity environment for a period of 2.2 seconds. It is used extensively by NASA research scientists as well as university principal investigators. The current focus of the programs utilizing the facility is in the areas of combustion science and fluid physics. The role of the Drop Tower in these areas includes the execution of ground-based science programs, the performance of precursor tests to define space experiment science requirements and conceptual designs, and the performance of tests for space experiment technology

development and verification. The Drop Tower is an ideal research facility, especially for exploratory tests, as it is operated at a relatively low cost and investigators participate directly in experiment build-up and testing. The extensive utilization of the Drop Tower is evident in the fact that over 19,000 research drops have been performed to date. Currently about 1800 drops are conducted each year.

The Drop Tower utilizes an experiment/drag shield system for its mode of operation. Experiments assembled on a drop frame structure are enclosed in a drag shield that has a high weight-to-frontal area ratio and a low drag coefficient. The drag shield/experiment assembly is hoisted to the top of the tower and released. The entire assembly falls freely and unguided in the open environment of the tower. The experiment is isolated from aerodynamic drag as it is contained within, but not attached to the drag shield. During the drop, the entire assembly falls 24.1 meters, and the experiment falls freely a distance of 20 cm within the drag shield. The package is decelerated in a 10 foot tall air bag. Battery packs provide on-board power to the experiment. Data is acquired by high speed motion picture cameras, video cameras, and on-board computers. Normal operations provide the opportunity for up to 12 drops per day to be performed.

Operational Parameters

- Low gravity duration: 2.2 seconds
- Normal atmosphere with drag shield system
- Acceleration environment: 10^{-3} - 10^{-4} g
- Deceleration levels: 15 to 30 g's for several milliseconds

Microgravity Emissions Laboratory (MEL)

The Microgravity Emissions Laboratory (MEL) is an inertial measurement system capable of characterizing on-orbit disturbers (i.e. equipment/source forcing functions) from 0.5 Hz to 300 Hz and down to 10^{-7} g's. These inertial forcing functions are derived from a moderate set of bi-axial accelerometers and the measured diagonal mass matrix. Currently MEL is outfitted to handle equipment along with the associated fixture to 300 Kg (750 lbm). Improvements are in the works to accommodate ISPR (Space Station/ SPACEHAB) sized racks. This will allow for the handling of 1000 kg racks along with 300 kg isolation fixture as required. The service is provided by the same team that operate the Structural Dynamics Laboratory (SDL).

The MEL is a developmental facility and the low frequency apparatus is being used to evaluate the acceleration emissions from various assemblies such as fans, hard drives and other component-level tests. Currently, the mass limit is 300 Kg (750 lbm) and the maximum size is 0.6 m x 0.6 m x 0.6 m (2 ft. x 2 ft. x 2 ft.). The facility noise floor was established by test in September 1999. Planned modifications to enable rack-level development testing will raise the mass limit to 900 Kg (2250 lbm) and increase the maximum size to 0.9 m x 1.0 m x 2.0 m (3 ft. x 3.5 ft. x 7 ft.).

Fluid and Combustion Facility (FCF) Engineering Models and U.S. Laboratory Mockup

This Fluids & Combustion Facility (FCF) equipment was fabricated for proof of concepts and engineering trade off studies during the initial design of the Fluid Integrated Rack (FIR), the Combustion Integrated Rack (CIR), and the Shared Accommodations Rack (SAR). The FCF is being developed by the Microgravity Science Division (MSD) at the NASA Glenn Research Center.

The FCF is a modular, multi-user facility to accommodate microgravity science experiments on board the US Laboratory Module of the International Space Station. The FCF will be a permanent facility aboard the ISS, and will be capable of accommodating up to ten science investigations per year. It will support the sustained systematic research of the effects of reduced gravity in the areas of fluid physics and combustion science.

Active rack isolation (ARIS) is integral to all three racks along with electrical power conversation and distribution, command and data management, image processing, communication interfaces with the ISS. The FCF will have rack closure doors. The environmental control subsystems will provide air thermal control, water thermal control, fire detection and suppression, and a nitrogen gas interface.

The three racks together will provide the physical and functional infrastructure required to perform combustion science, fluids physics and adjunct science on-board the ISS.

The facility will be launched incrementally in three separate, integrated racks beginning in 2001. The first rack launched will be the CIR, the second will be the FIR; and the third will be the SAR. In 2003, the FCF will be complete with the addition of the SAR. The FCF in its assembly complete flight configuration will add additional science experiment capabilities.

Next MGMG Meeting

MGMG #20 will most likely be held in mid-year 2001 at the NASA Glenn Research Center in Cleveland, Ohio. At that time (according to current schedules), the SAMS-II and MAMS should be operating on-board the ISS. If possible, acceleration data will be available in the meeting room to allow demonstration of real-time processing and analysis. Bjarni Tryggvason offered that the Canadian Space Agency could host a future MGMG meeting in either Montreal or in Toronto.

The regular topics of sensors, accelerometer systems, analysis results, vibration isolation, microgravity environment, and science effects will continue to be included.

2/11 8001017 7 512558 21ps

Paper Number: 1

Space Acceleration Measurement Systems

William Foster
NASA Glenn Research Center
Cleveland, Ohio

The Space Acceleration Measurement Systems (SAMS) Project develops and deploys the measurement systems for the Acceleration Measurement Program (AMP). At this time there are two types of measurement systems available, quasi-steady and vibratory. Orbital Acceleration Research Experiment (OARE) and Microgravity Acceleration Measurement System (MAMS) are the current quasi-steady systems available. OARE has flown numerous times supporting STS missions. MAMS has been delivered to Kennedy Space Center (KSC) for its deployment on the International Space Station (ISS). Vibratory measurements have been made and will be made by the Space Acceleration Measurement System (SAMS-I) Generation I, Space Acceleration Measurement System Generation II (SAMS-II), and Space Acceleration Measurement System Free Flyer or Generation III (SAMS-FF). SAMS-I supported 21 STS missions and has been retired. SAMS-II will be delivered to KSC to support ISS-6A launch (currently April 19, 2001). SAMS-FF has replaced SAMS-I in support of STS missions and has been deployed on sounding rockets, the KC-135 and ground facilities. SAMS-FF hardware shall be deployed on ISS in the future to provide a more compact solution.

John H. Glenn Research Center
at Lewis Field

Cleveland, Ohio

Space Acceleration Measurement Systems (SAMS)

July 11, 2000

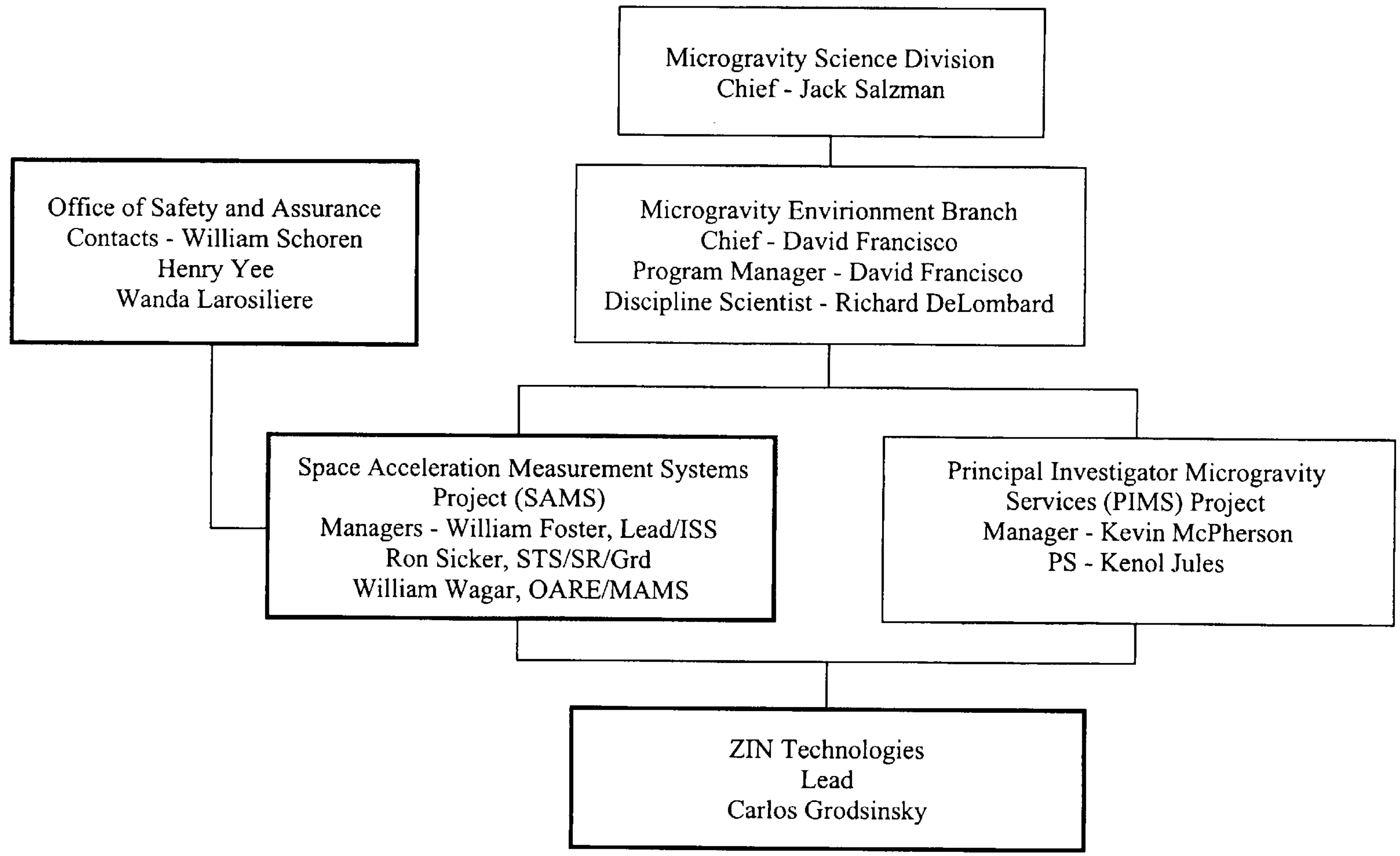
Glenn Research Center

Presentation Agenda

- Organization & Purpose
- Past, Present and Future
- ISS Customers and Requirements
- ISS Measurement Systems Overview
- Descriptions and Initial Deployment for ISS
- Present Status (SAMS-II)

Glenn Research Center

Acceleration Program at GRC



July 11, 2000 MGMG 2000 3

SAMS Purpose

- Develop, deploy, and operate acceleration measurement systems to measure, collect, process, record, and deliver selected acceleration data to researchers & other customers that require control, monitoring and characterization of a microgravity environment on platforms such as drop towers, aircraft, Shuttle, and ISS.

Glenn Research Center

Acceleration Measurement History

- NASA Glenn Systems
  - Space Acceleration Measurement System (SAMS)
    - 20 Shuttle Flights, 7 Units (1991 to 1998)
    - Measured Acceleration Range: 0.01 to 100 Hz
  - Orbital Acceleration Research Experiment (OARE)
    - 8+ Shuttle Flights, 1 Unit (1991 to Present)
    - Measured Acceleration Range: DC to 1 Hz
- Microgravity Environment Description Handbook (NASA TM 107486)
- Acceleration Data Stored on Web Server
- Other Systems
  - High Resolution Accelerometer Package (HiRAP), JSC/LARC
  - 3-Dimensional Microgravity Accelerometer (3DMA), UAH
  - Microgravity Measurement Device (MMD), JSC
  - Quasi-Steady Acceleration Measurement (QSAM), DLR
  - Microgravity Measurement Assembly (MMA), ESTEC/ESA

SAMS Present & Future

- Space Acceleration Measurement System Generation II (SAMS-II)
  - Initiated Studies 1992
  - Modular expandable system to support ISS
  - Initial deployment on ISS-6A, April 19, 2001
  - Measured Acceleration Range: 0.01 to 300 Hz
- Microgravity Acceleration Measurement System (MAMS)
  - OARE repackaged for ISS
  - Deployment on ISS-6A, April 19, 2001
  - Measures Acceleration Range: DC to 1 Hz
- Space Acceleration Measurement System Generation III (SAMS-FF)
  - Goal to reduce size of the sensor for Sounding Rockets
  - Replaced original SAMS on shuttle
  - Will be deployed on ISS in the Fluids and Combustion Facility
- SAMS Generation IV
  - Combination of existing systems and upgrades
  - Control Unit (CU) for ISS; replaces Interim Control Unit (ICU)

Glenn Research Center

ISS Support Overview

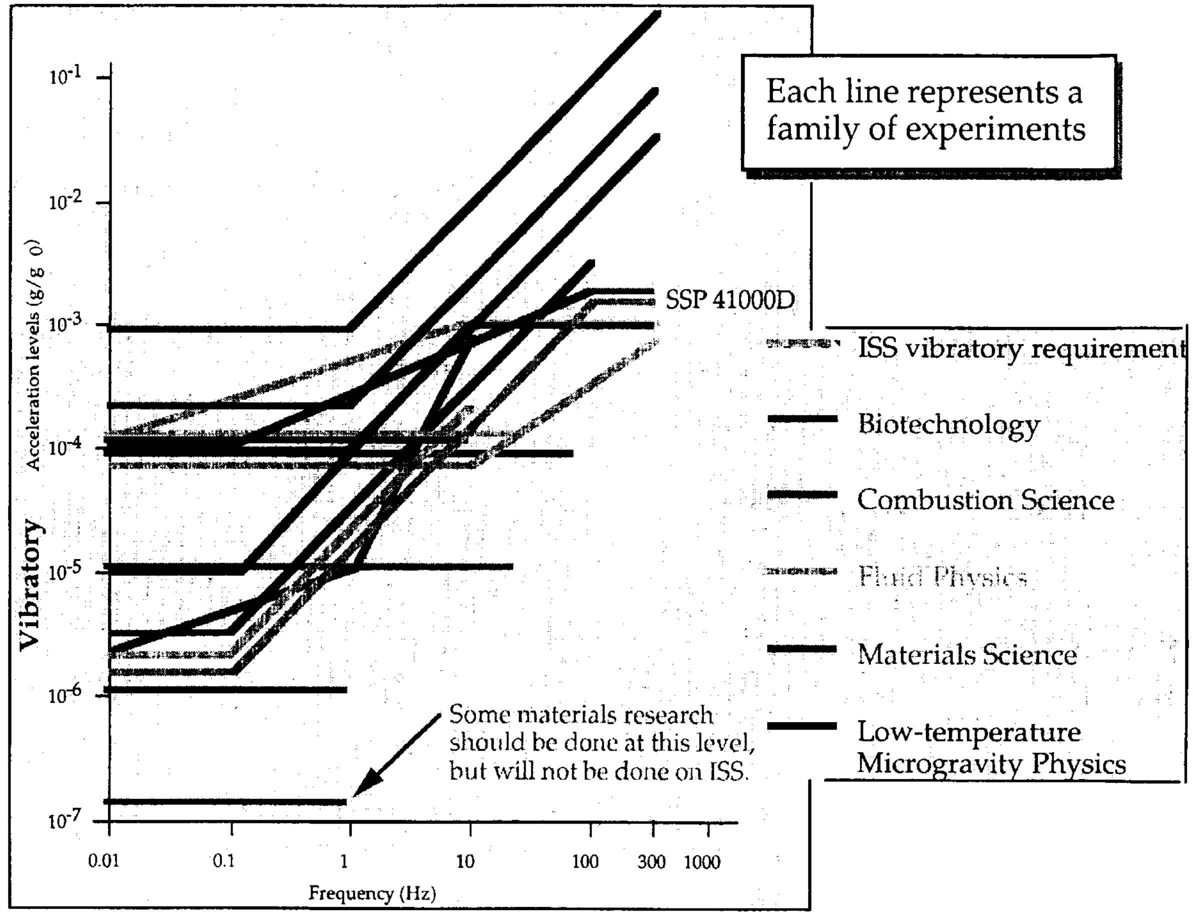
- Purpose on ISS
  - To measure, collect, process, record, and downlink selected acceleration and health monitoring data for various microgravity payloads and vehicle characterization aboard the ISS.

- Components on ISS
  - Interim Control Unit (ICU) from 6A to UF-3, Control Unit (CU) thereafter
  - Remote Triaxial Sensor (RTS) System (EE + 1 or 2 SE's)
    - Up to Ten RTS Electronics Enclosures (EE's)
    - Up to Two RTS Sensor Enclosures (SE's) per EE
    - Two RTS Drawers for ARIS ICE for 6A - Modified ISIS Drawers containing one EE and two SE's (SE's are normally mounted outside of drawer)
  - Microgravity Acceleration Measurement System (MAMS)
  - Future deployment of Generation III & IV measurement systems

Glenn Research Center

Microgravity Environment Measurement Requirements

- Vibratory:
  - Ranges from milli-g to sub-μg
- Quasi-Steady:
  - Below 1 μg
- Multiple payloads
- Minimize use of Resources
- Distribute data



Glenn Research Center

SAMS ISS Customers

- Microgravity science payloads
- ISS Vehicle

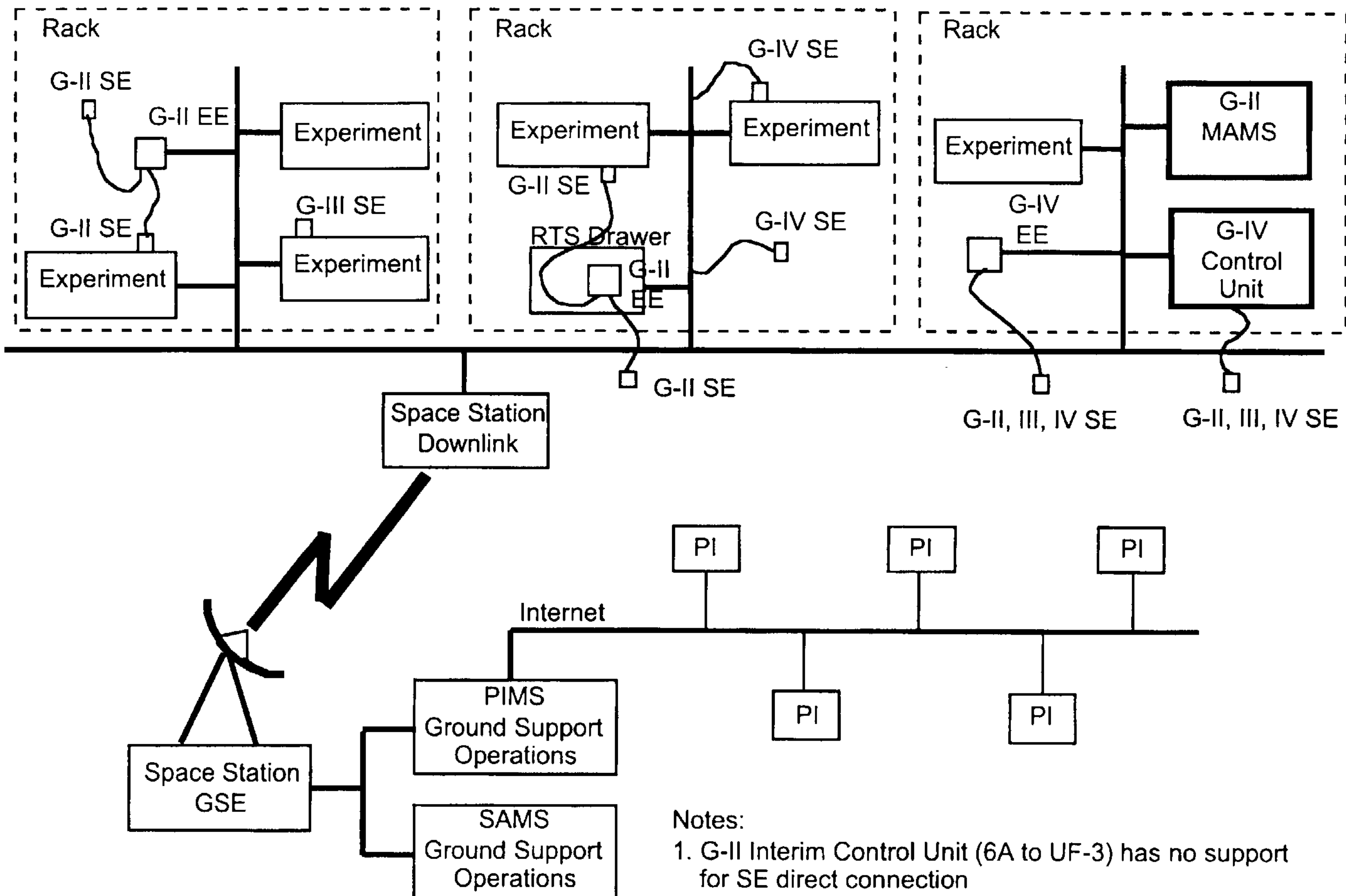
Customer and Location	Delivery Date
EE #1 to EXPRESS Rack #2 (returned for inspection)	8/1999
EE #5 to EXPRESS Rack #2	7/2000
ICU Drawer to KSC	8/2000
RTS Drawer #1 & #2 to KSC (ARIS-ICE)	10/2000
SE #1 to PCS	12/2000
EE #4 to EXPRESS Rack #3	12/2000*
EE #6 to EXPRESS Rack #7	1/2001*
EE #1 to EXPRESS Rack #8	2/2001*
EE#7 to Microgravity Science Glovebox	TBD

* Under Review

- Other units to be supplied to the Materials Science Facility, Fluids and Combustion Facility, and other customers. Delivery dates estimated to be L-12.
- Data services provided by the Principal Investigator Microgravity Services (PIMS) Project.
- MAMS is an ISS System and is requested as a resource (iURC)

Glenn Research Center

System Overview on ISS



Notes:

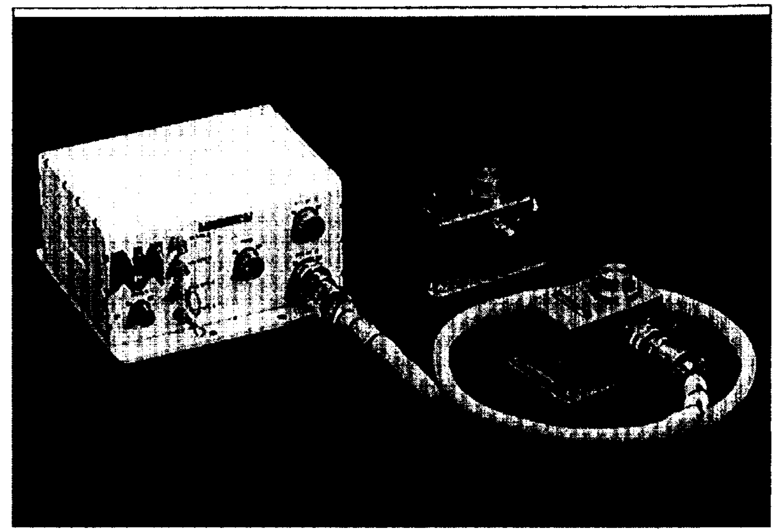
1. G-II Interim Control Unit (6A to UF-3) has no support for SE direct connection
2. G-II Elements available 6A.
3. G-III Elements available UF-1.
4. Control Unit available UF-3.

Glenn Research Center

Description and Initial Deployment for International Space Station

Remote Triaxial Sensor (RTS) System

- Components
  - Physical Properties: 9.1 in x 9.3 in. x 4.7 in. & 11.0 LB
  - PC/104 card stack (CPU, Ethernet, A/D, Control, Interface(2))
  - Mil-grade DC/DC converters & EMI Filter
  - **Sensor Enclosure (SE)**
  - Physical Properties: 5.6 in X 4.0 in. X 3.5 in. & 2.5 LB
  - Pendulous servo accelerometers (3 QA-3000/3100 units)
  - Temp compensation (in QA-3000/3100s)
  - Alignment- orthogonality 0.1°; to base 0.5°
  - Delta Sigma 24 bit A/D Converter per axis
  - Custom Interface Cable (EE to SE's)
- Slave to Interim Control Unit (ICU)
- Sends data to ICU across Ethernet
- Measures, digitizes, & compensates acceleration data (0.01 to 300 Hz)
- Dynamic Range: 130 dB (0.1 μg to 1g)
- Selectable Frequency Ranges: 300, 200, 100, 50, 25 Hz
- EE mounts in racks, SE on payloads



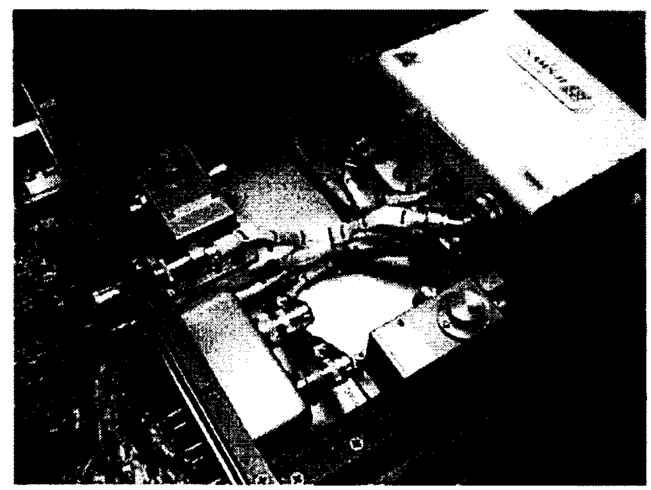
Shipments
- Shipped - EE 122-F01 EXPRESS #2
- 7/17/2000 - EE 122-F05 EXPRESS #2
- 11/15/2000 - SE 121-F06 to PCS (6A)
- 12/2000 to 2/2000 - EE 122-F04, F06, F01 EXPRESS

Glenn Research Center

Remote Triaxial Sensor (RTS) Drawer

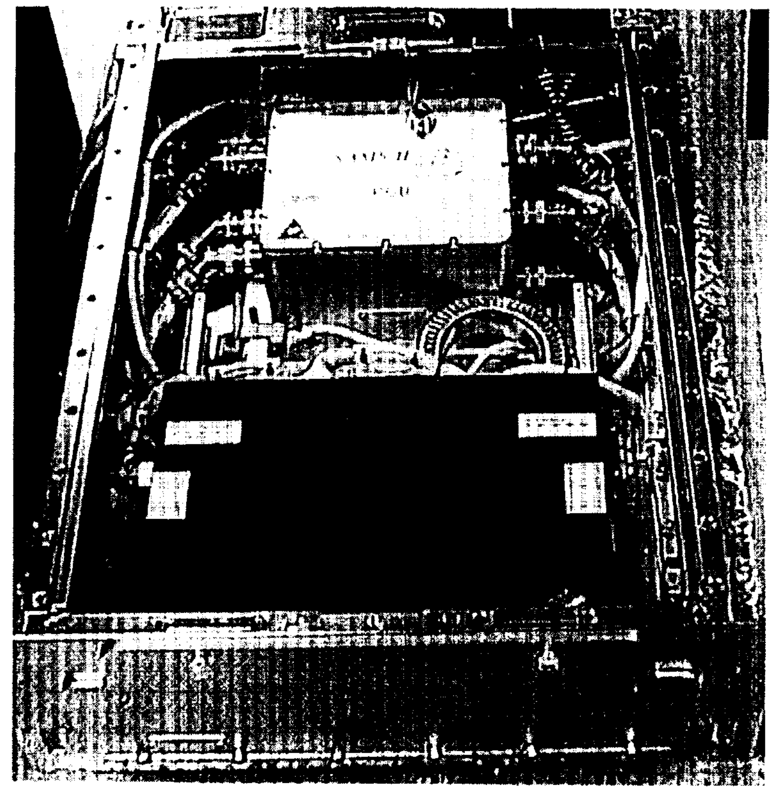
- Components
  - Modified ISIS Drawer
  - RTS System
    - 2 Sensor Enclosure (SE)
  - Fan Assembly (Spare in stowage)
  - Switch/breaker box
  - Cables
- Ethernet connection, 28 Volt Power
- 1 SE can be operated in drawer
- Both SE's can be mounted external
- Can be moved to any Rack with a powered ISIS/CIR Drawer Slot
- On-orbit change-out of components
- Shipments

  10/16/2000 - RTS Drawer 314-FD01&FD02 (6A)



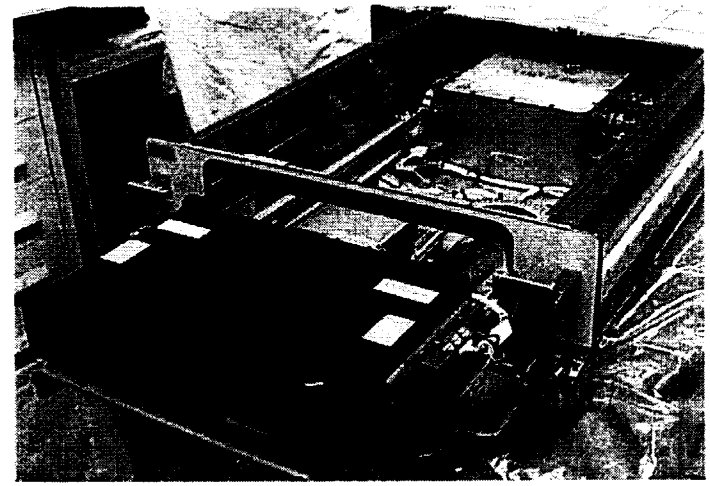
Interim Control Unit (ICU)

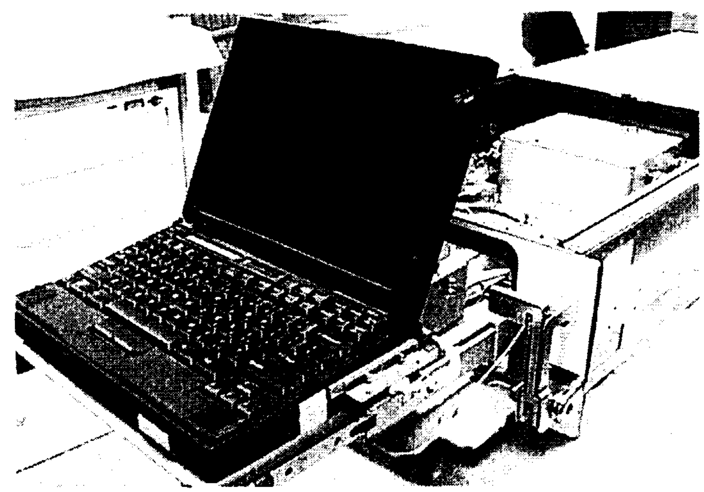
- Components
  - Modified ISIS Drawer
  - **ISS Portable Computer System (PCS)**
    - Spare in PCS pool
    - IBM 760XD, two 3GB hard drive
    - Certified by JSC ISS PCS
  - **Power Control Box (PCB)**
    - Power conditioning (+20,+16.5,+5)
    - Battery charging
    - Health monitoring circuitry
    - Spare in stowage
  - Circuit Breaker box
  - Fan Assembly (Spare in stowage)
  - Temperature Sensors
  - Spare hard drive w/flight software
- Ethernet connection, 28 Volt Power
- Acquires data from Electronic Enclosure (EE)
- Downlinks data, Receives uplink commands
- On-orbit change-out of components
- Shipments
  7/31/2000 - ICU 171-FD01 (6A)



Glenn Research Center

Interim Control Unit (ICU) Capability



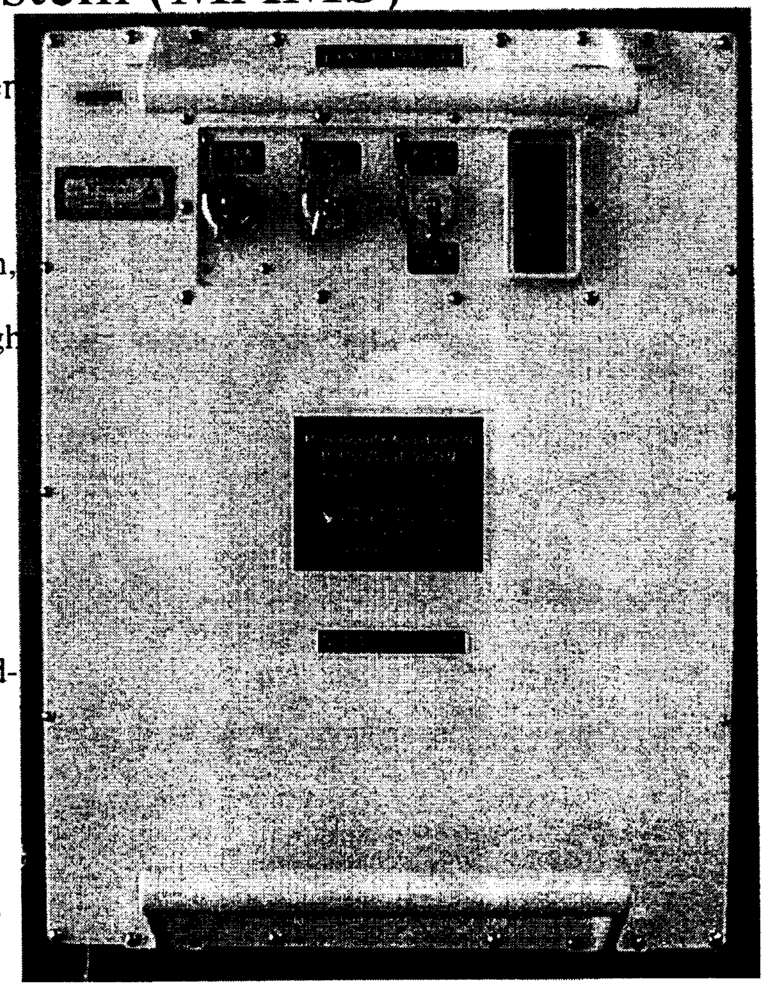


- PCS Laptop mounted on a slide out drawer for astronaut access
  - Approved crew displays
  - Crew configures EE's with laptop
  - New system software loads
- Supports 20 triaxial sensors @ 300 Hz
- Stores approx. 4 hours of data
- Downlinks data
- Receives ground commands to control distributed Ethernet sensors
- ISS-6A to UF-3, Control Unit (CU) thereafter

Glenn Research Center

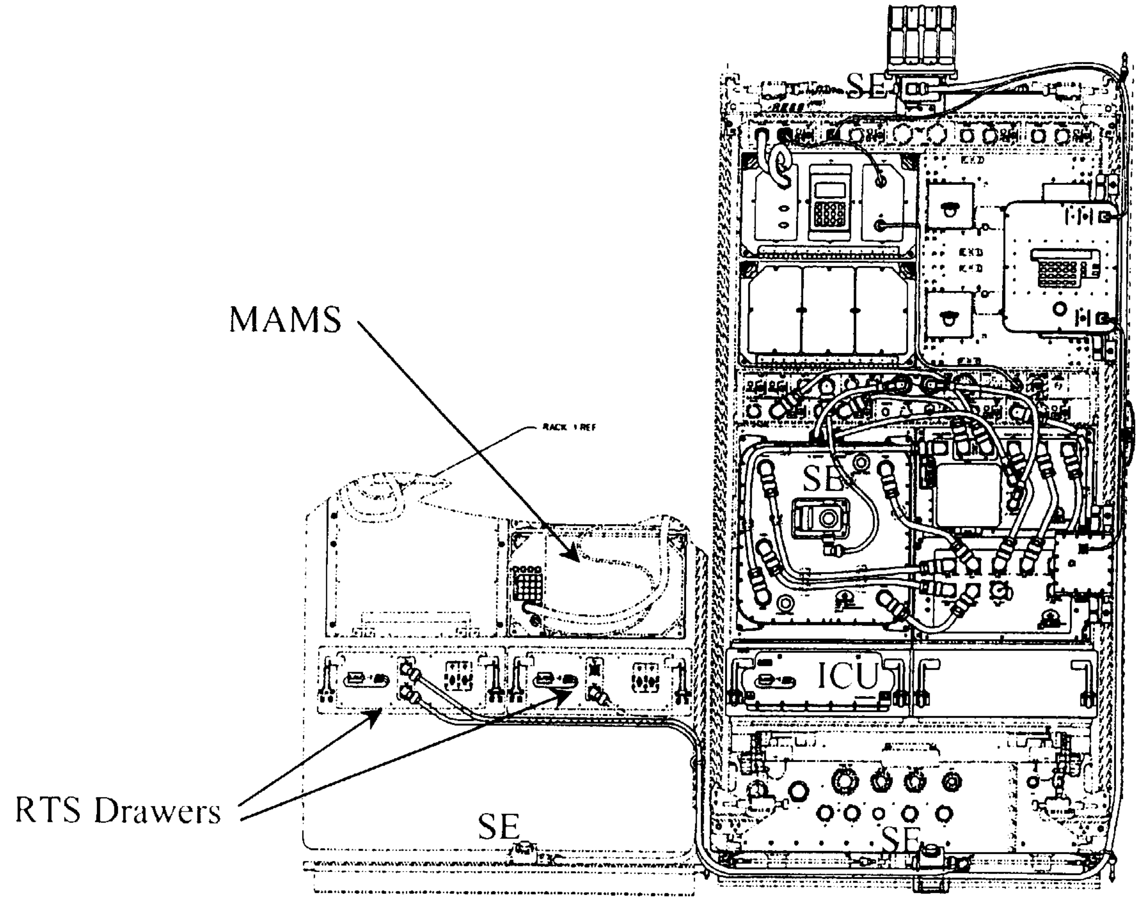
Microgravity Acceleration Measurement System (MAMS)

- Components & Capabilities
  - Miniature Electro-Static Accelerometer (MESA)
    - Frequency Range: DC to 1 Hz
    - Resolution of 3×10^{-9} g.
    - Electro-statically suspended, beryllium, cylindrical proof-mass which is kept centered within an outer "cage" through the use of forcing electrodes.
    - Forcing voltage required to keep cylinder centered is proportional to outer cage acceleration.
  - Bias Calibration Table Assembly (BCTA)
    - measurement of the sensor bias.
    - Sensor bias: electro-static charge build-up & temp. gradients on beryllium cylinder proof-mass.
    - Correcting acceleration data for bias results in an expected accuracy of approximately 50×10^{-9} g.
- Double Middeck Locker (EXPRESS Rack)
- Shipments: 5/2000 - ISS 6A



Glenn Research Center

SAMS in EXPRESS Racks No.1 & 2 for 6A Flight Configuration



Glenn Research Center

SAMS-II System Schedule Highlights

- July 10-14 Vibration Test of ICU, RTS Drawers
- July 13 Phase III Flight Safety Review (ICU/RTS Drawers)
- July 14 Executive PSR for EE 121-F04 & F05
- July 17 Engineering PSR - Formal Presentation
- July 17 Ship EE 122-F05 to EXPRESS
- July 17-19 Thermal Test of ICU, RTS Drawers, Spares
- July 20-21 System Load Test (some operations during thermal test)
- July 28 Executive PSR for ISS-6A Hardware & Software
- July 31 ICU ship to KSC
- August 7 Turnover ICU for integrated testing
- October 16 RTS Drawers, SE 121-F06, ICU software to KSC
- October 25 All above turnover, ISS-6A
- November PTCS Testing
- November SE's returned for final calibration
- December Spares and SE's ship for stowage in MPLM
- April 19, 2001 Launch ISS-6A

Glenn Research Center

SAMS ISS Traffic Model

Increments Flights System Components Available	2 6A 4/19/2001	3 7A.1 6/21/2001	3 UF-1 8/23/2001	4 UF-2 1/17/2002	UF-3 10/16/2003	UF-5 6/24/2004	17A 1/20/2005	HTV2	UF-6 7/15/2005
MAMS	ER #1	ER #4	ER #4	ER #4	ER #4				
Interim Control Unit	ER #2	ER #1	ER #1	ER #1	Down				
RTS Drawer 314-F01 (EE 122-F02)	ER #1	ER #1	ER #1	ER #1	ER #1				
Sensor Enclosure 121-F02	ARIS-ICE		MSG?		Down				
Sensor Enclosure 121-F03	ARIS-ICE				Down				
RTS Drawer 314-F02 (EE 122-F03)	ER #1	ER #4	ER #4	ER #4	ER #4				
Sensor Enclosure 121-F02	ARIS-ICE				Down				
Sensor Enclosure 121-F03	PIMS				Down				
Sensor Enclosure 121-F06	PCS	PCS	PCS	Down					
Electronics Enclosure 122-F05	ER #2	ER #2	ER #2	ER #2	ER #2	ER #2	ER #2	ER #2	ER #2
Electronics Enclosure 122-F04				ER #3	ER #3	ER #3	ER #3	ER #3	ER #3
Electronics Enclosure 122-F06							ER#7	ER#7	ER#7
Electronics Enclosure 122-F01							ER#8	ER#8	ER#8
Electronics Enclosure 122-F07			MSG?	MSG?	Down				
Sensor Enclosure 121-F01			MSG?	MSG?	Down				
Electronics Enclosure 122-F08					MSRR	MSRR	MSRR	MSRR	MSRR
Sensor Enclosure 121-F07					MSRR	MSRR	MSRR	MSRR	Down
Triaxial Sensor Head -001					CIR	CIR	CIR	CIR	Down
Triaxial Sensor Head -002						FIR	FIR	FIR	FIR
Triaxial Sensor Head -003									CIR
Triaxial Sensor Head -e001					MSG	MSG	MSG	MSG	Down
Triaxial Sensor Head -013								LTMPF	LTMPF
Triaxial Sensor Head -014								LTMPF	LTMPF
Control Unit -001					ER #1	ER #1	ER #1	ER #1	ER #1

ER = EXPRESS Rack
PCS = Physics of Colloids in Space
ARIS ICE = ARIS Initial Characterization Experiment

July 11, 2000 MGMG 2000 19

Glenn Research Center

Contact Information

- NASA Glenn Research Center

  William (Bill) Foster II - SAMS Project Manager

  216-433-2368

  W.M.Foster@grc.nasa.gov

- ZIN Technologies

  Carlos Grodsinsky - Acceleration Program Lead

  216-977-0316

  Carlos.M.Grodsinsky@grc.nasa.gov

  John Heese - SAMS Lead

  216-977-0418

  John.A.Heese@grc.nasa.gov

-3/19

5/2
43P

Paper Number: 2

2001019713

Microgravity Acceleration Measurement System (MAMS) flight configuration verification and status

William Wagar
NASA Glenn Research Center
Cleveland, Ohio

James Fox
Canopus Systems
Ann Arbor, Michigan

The Microgravity Acceleration Measurement System (MAMS) is a precision spaceflight instrument designed to measure and characterize the microgravity environment existing in the US Lab Module of the International Space Station. Both vibratory and quasi-steady triaxial acceleration data are acquired and provided to an Ethernet data link. The MAMS Double Mid-Deck Locker (DMDL) EXPRESS Rack payload meets all the ISS IDD and ICD interface requirements as discussed in the paper which also presents flight configuration illustrations. The overall MAMS sensor and data acquisition performance and verification data are presented in addition to a discussion of the Command and Data Handling features implemented via the ISS downlink and the GRC Telescience Center displays.

MAMS Presentation

Canopus Systems

Microgravity Acceleration Measurement System (MAMS)
ISS Flight Configuration Verification and Status

Presentation to Microgravity Measurement Group Meeting #19
Cleveland, OH 11 July, 2000

By: James C. Fox
MAMS Program Manager
Canopus Systems Inc.

and William O. Wagar
OARE/MAMS Project Manager
NASA Glenn Research Center

MAMS Mission

Canopus Systems

- The mission of the Microgravity Acceleration Measurement System (MAMS) is to measure and report vibratory (>1Hz) and quasi-steady acceleration (<1Hz) within the United States Laboratory Module on the International Space Station.
- MAMS acceleration data will be utilized in the following scientific investigations:
  - Microgravity Environment Verification
  - Low-Frequency Vehicle Dynamics Analysis
  - Combustion, Fluid Physics and Materials Microgravity Science Experiments
  - Attitude Control System Analysis
  - Atmospheric Drag Estimation

ISS Microgravity Acceleration Measurement System (MAMS) Functional Requirements

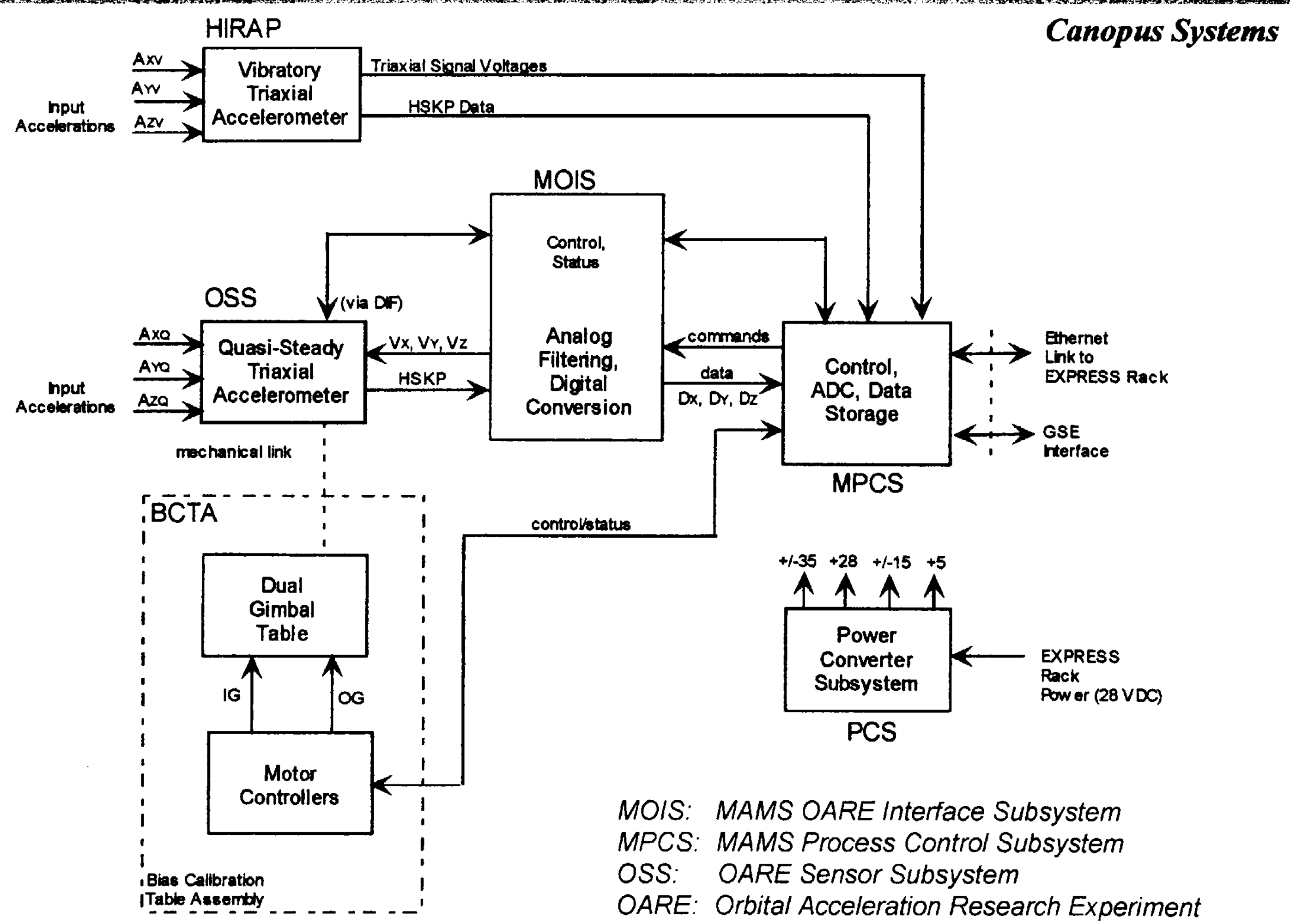
Canopus Systems

MAMS Shall Measure:

- Unisolated vibratory and quasi-steady accelerations at its installed EXPRESS Rack location within the US Laboratory module
- Quasi-steady accelerations in three orthogonal MESA sensor input axes, with an accuracy and resolution of 100 nano-g or better from the orbital rate to 1.0 Hz
- Vibratory accelerations in three orthogonal HIRAP sensing input axes, with an accuracy and resolution of 1/10th of the magnitude or one microgravity, whichever is greater, of the Space Station system acceleration limits from 0.01 Hz to 100 Hz (bandwidth change, PDR version 300 Hz)
- MAMS shall make available, when commanded, the vibratory and quasi-steady acceleration environment measurements to the Rack Interface Controller (RIC) along with the required Health and Status data (per IDD requirements)

MAMS Functional Block Diagram

Canopus Systems



MOIS: MAMS OARE Interface Subsystem
MPCS: MAMS Process Control Subsystem
OSS: OARE Sensor Subsystem
OARE: Orbital Acceleration Research Experiment

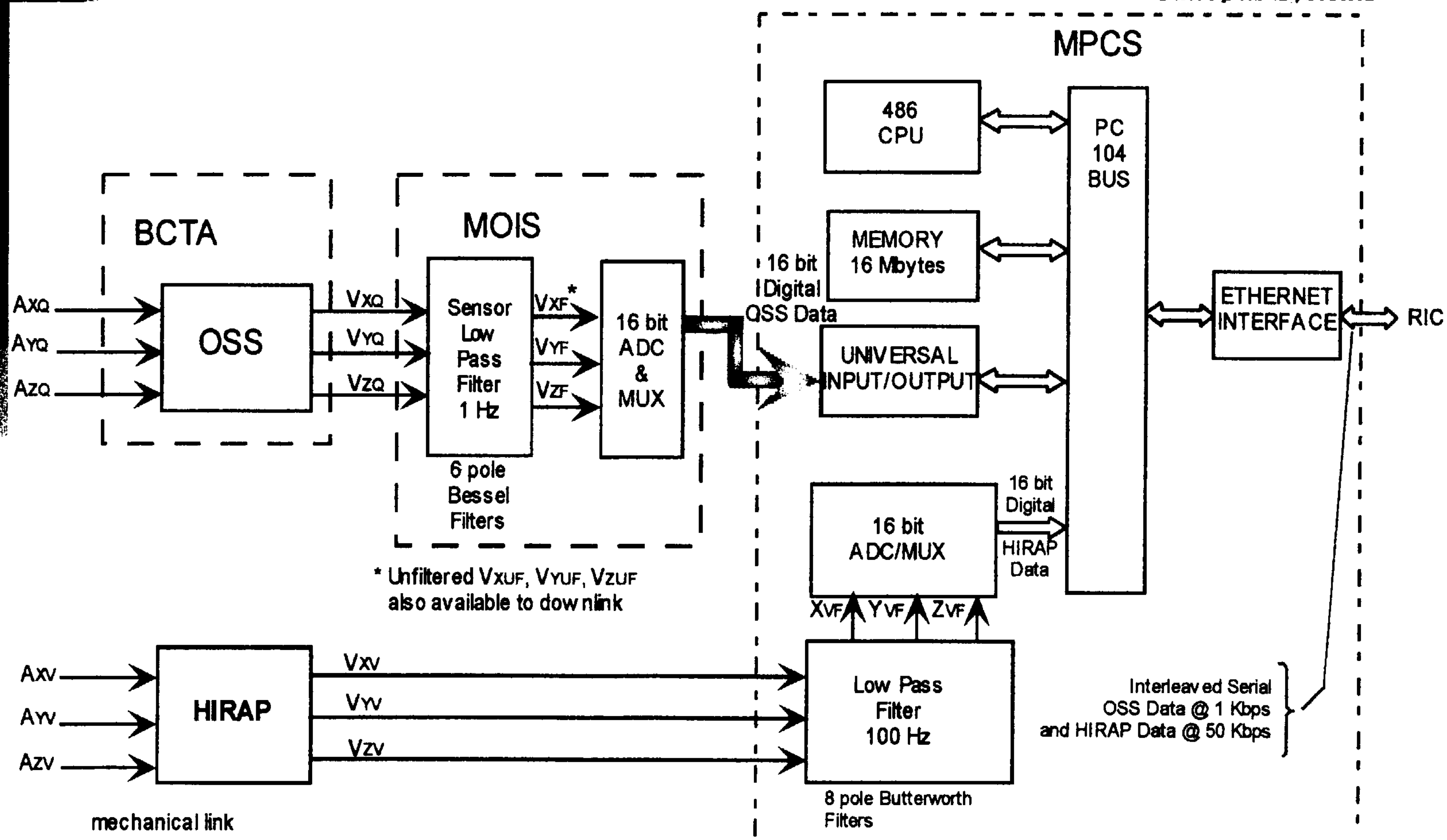
MAMS Calibrated Data Performance Requirements

Canopus Systems

Quasi-Steady Data (OSS MESA)	Parameters	
	X-axis	Y, Z Axes
C Range Resolution	3.05 nano-g	4.6 nano-g
C Range Accuracy	± 100 nano-g	± 150 nano-g
C Range Full Scale	± 100 micro-g	± 150 micro-g
B Range Full Scale	± 1.0 milli-g	± 1.97 milli-g
A Range Full Scale	± 10 milli-g	± 25 milli-g
Pre-Sample Filter Bandwidth	10^{-5} to 1.0 Hz	
Maximum Data Rate	1.0 Kbps	
Input Axis Alignment to Reference	± 20 arc minutes	
IA Positioning Accuracy	5 arc minutes	
Bias Temperature Coefficient	0.05 μg/°C	
Vibratory Data (HIRAP)		
Resolution and Accuracy (DSP output)	± 1.0 micro-g (± 10^{-6} g)	
Full Scale Dynamic Range	± 16 milli-g (± 16×10^{-3} g)	
Pre-Sample Filter Bandwidth	10^{-4} to 100 Hz	
Maximum Data Rate	52 Kbps	
Input Axis Alignment to Reference	± 10 arc minutes	
Bias Temperature Coefficient (Max)	10 μg/°C	

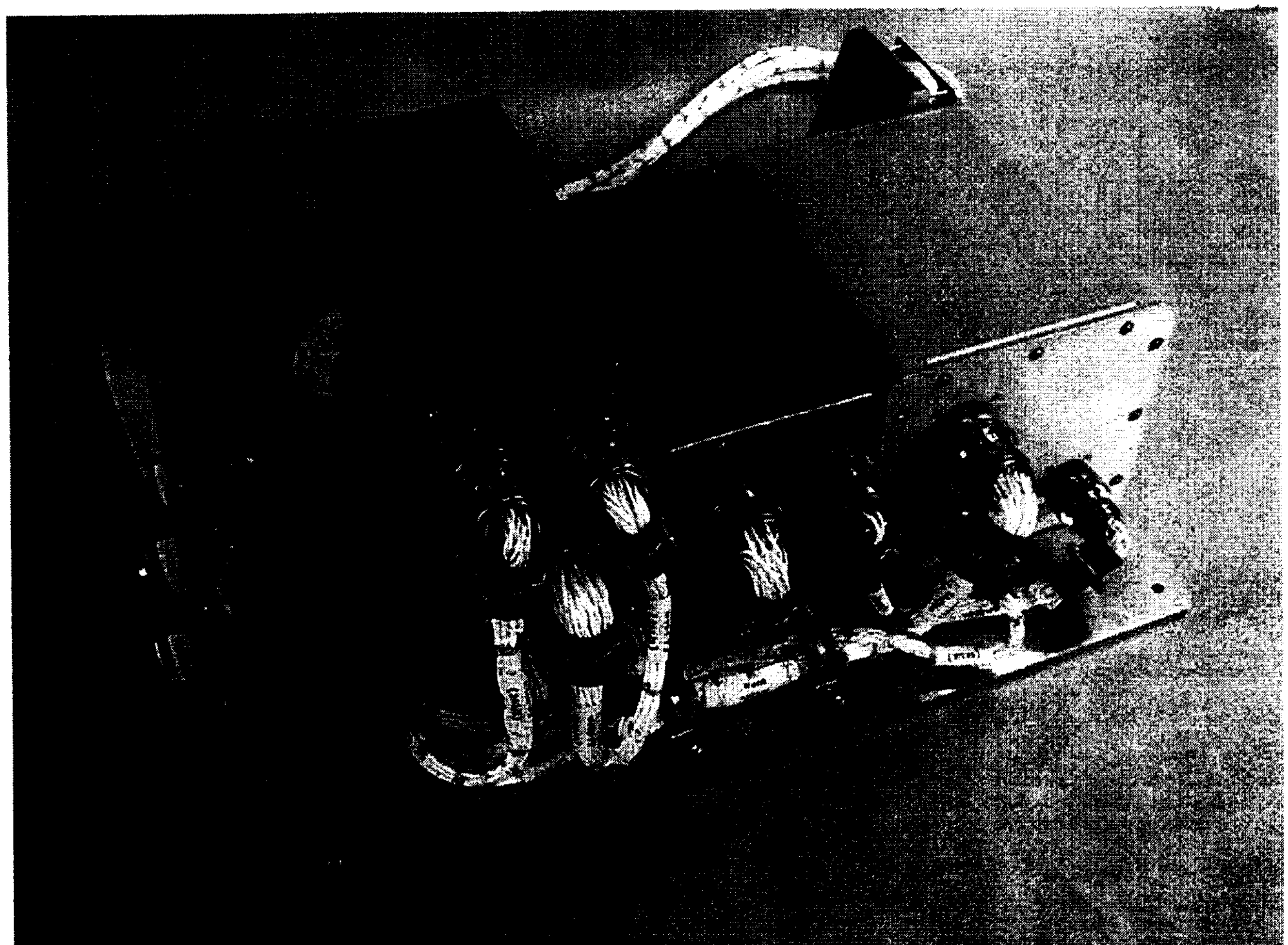
MAMS Data Path Block Diagram

Canopus Systems



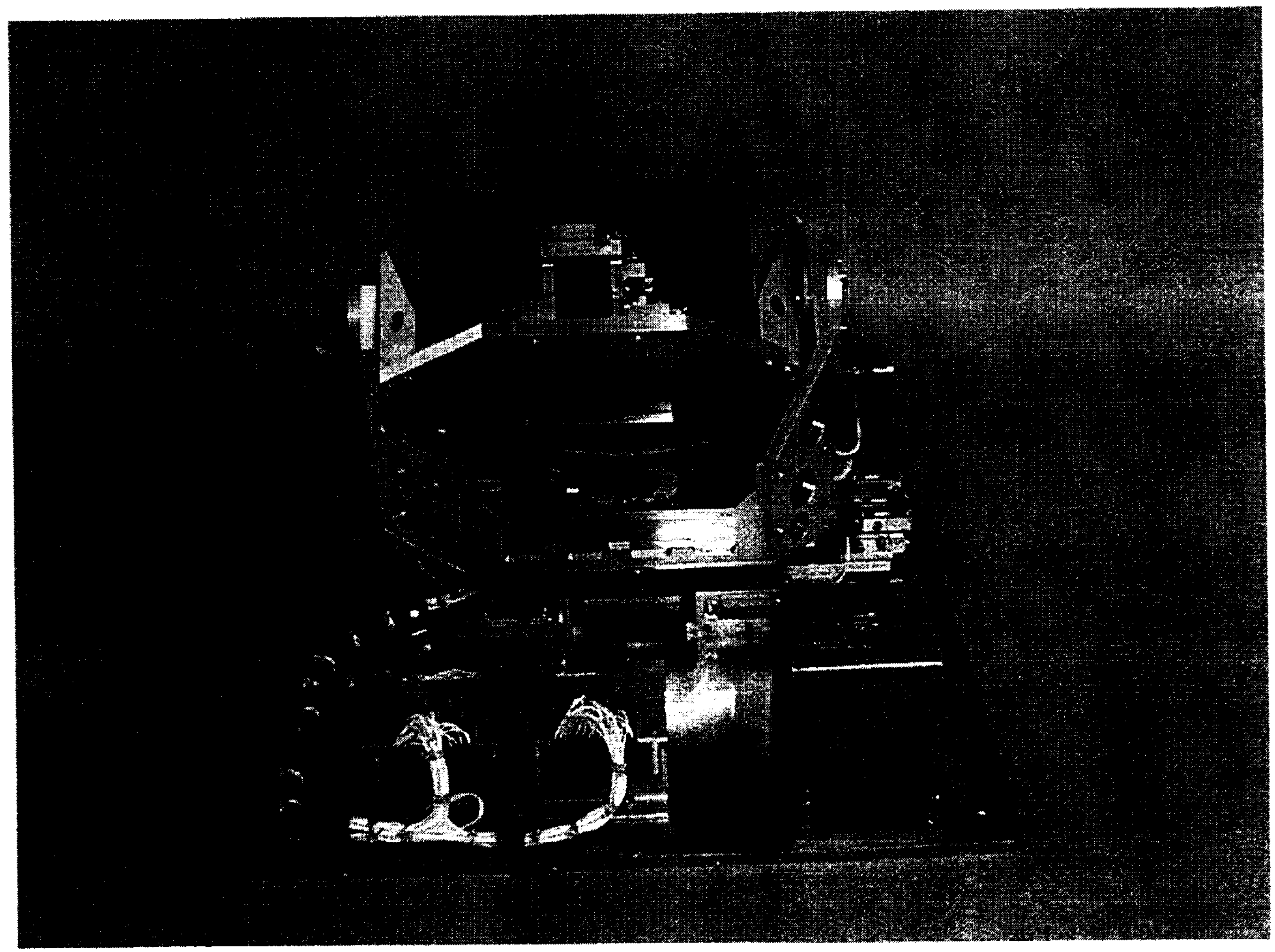
MAMS Upper Subplate Assembly

Canopus Systems



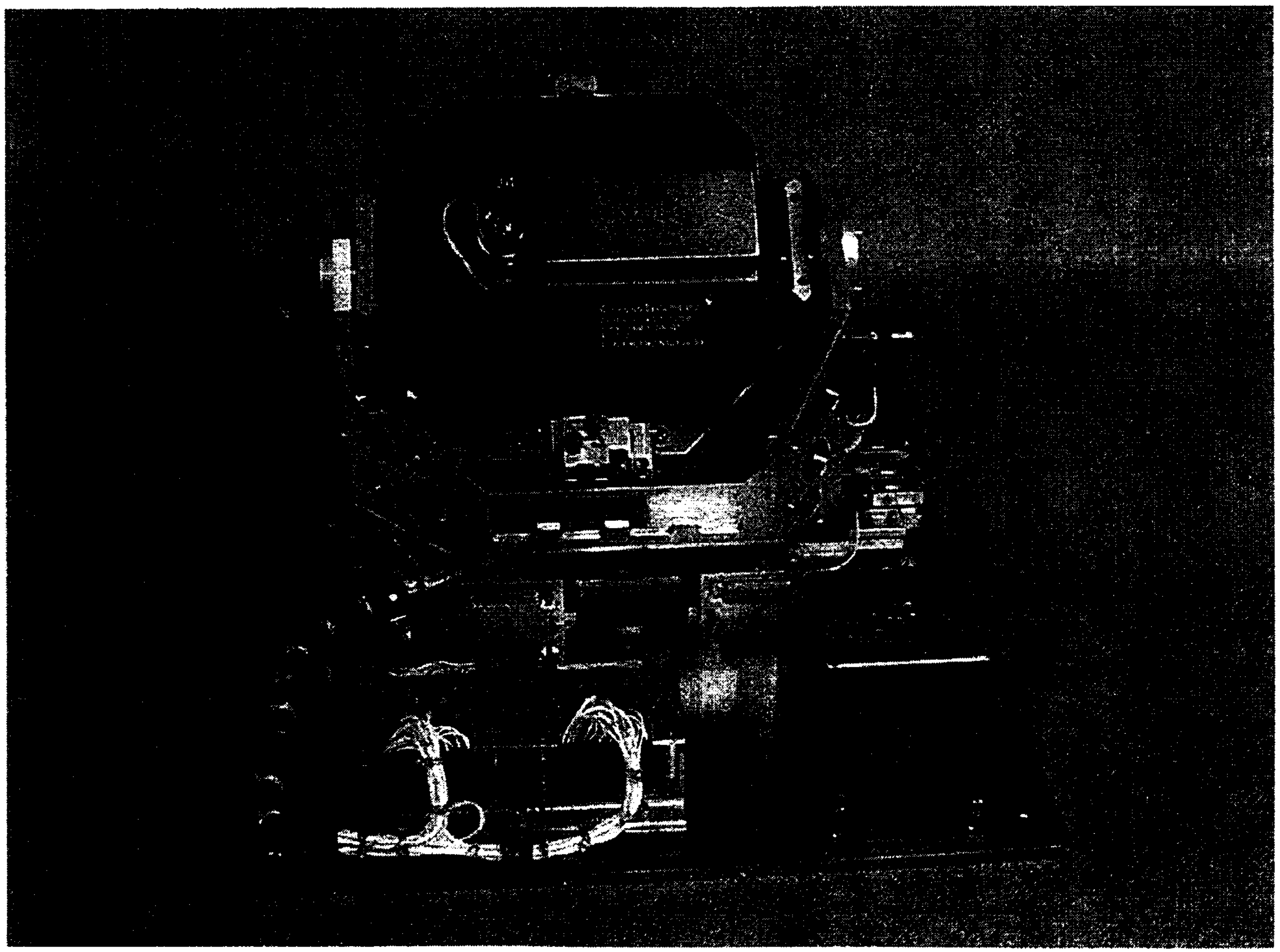
MAMS Lower Subplate Assembly (OG 0°, IG 0°)

Canopus Systems



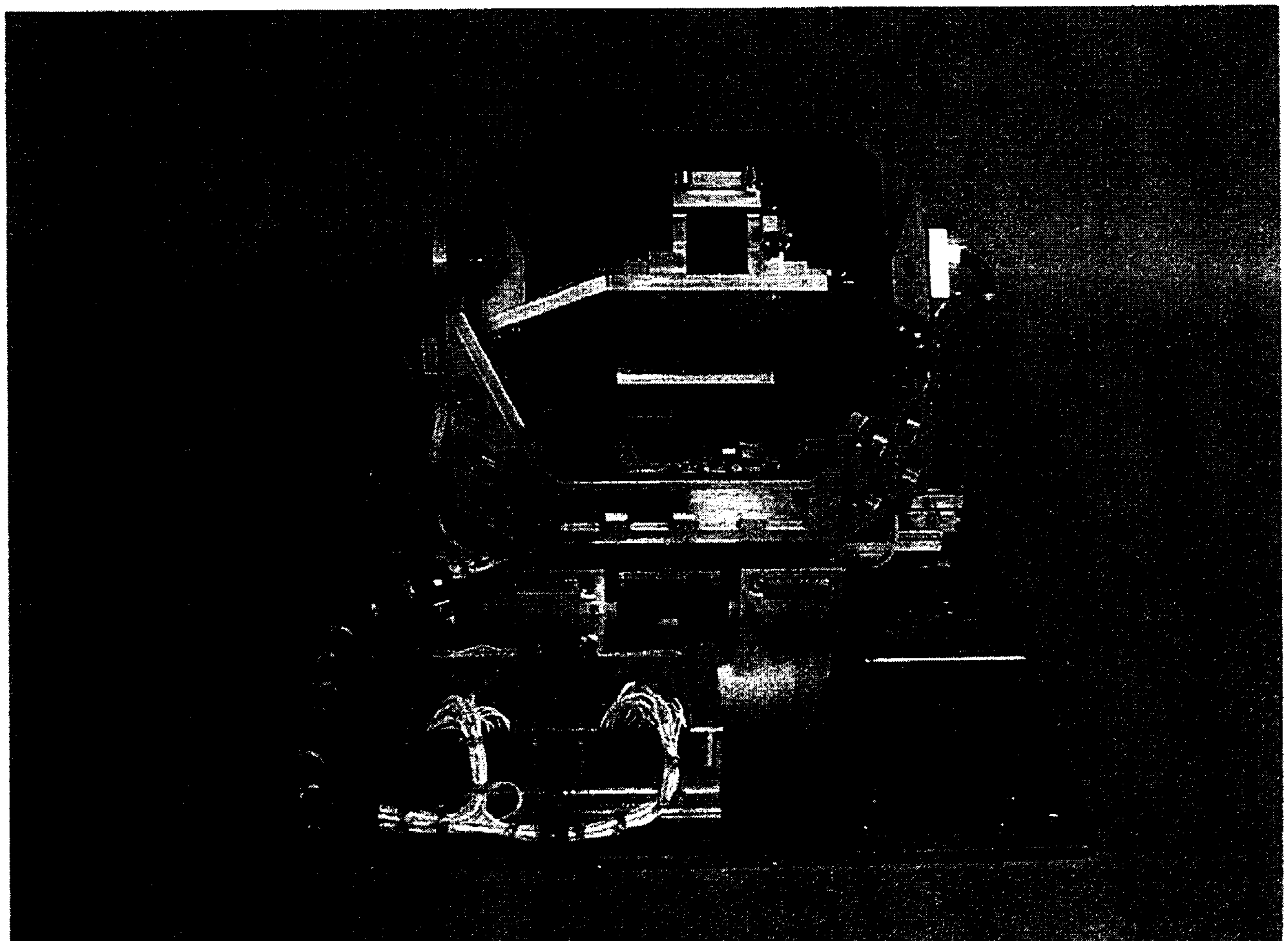
MAMS Lower Subplate Assembly (OG 0°, IG 90°)

Canopus Systems



MAMS Lower Subplate Assembly (OG 180°, IG 90°)

Canopus Systems

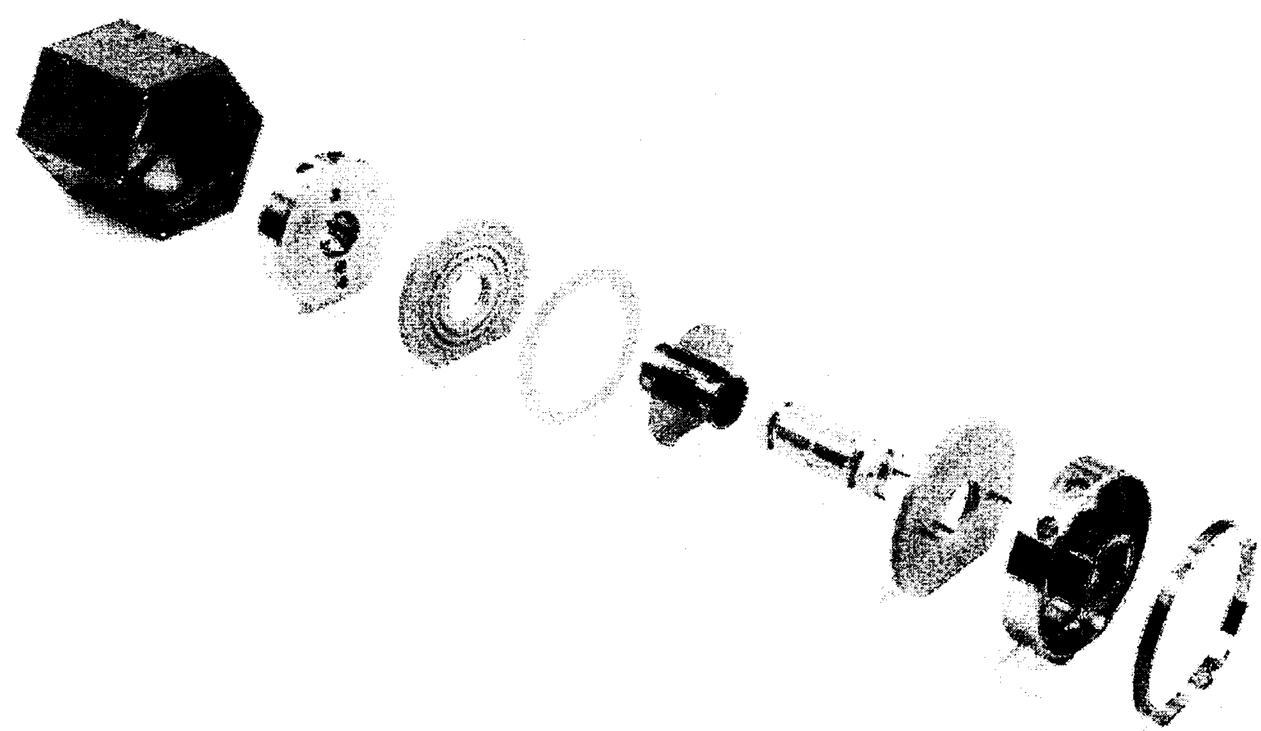


Spare OSS LRU

Canopus Systems

Miniature ElectroStatic Accelerometer (MESA)

Canopus Systems



Quasi-Steady (OSS) Acceleration Channels Characterization Data

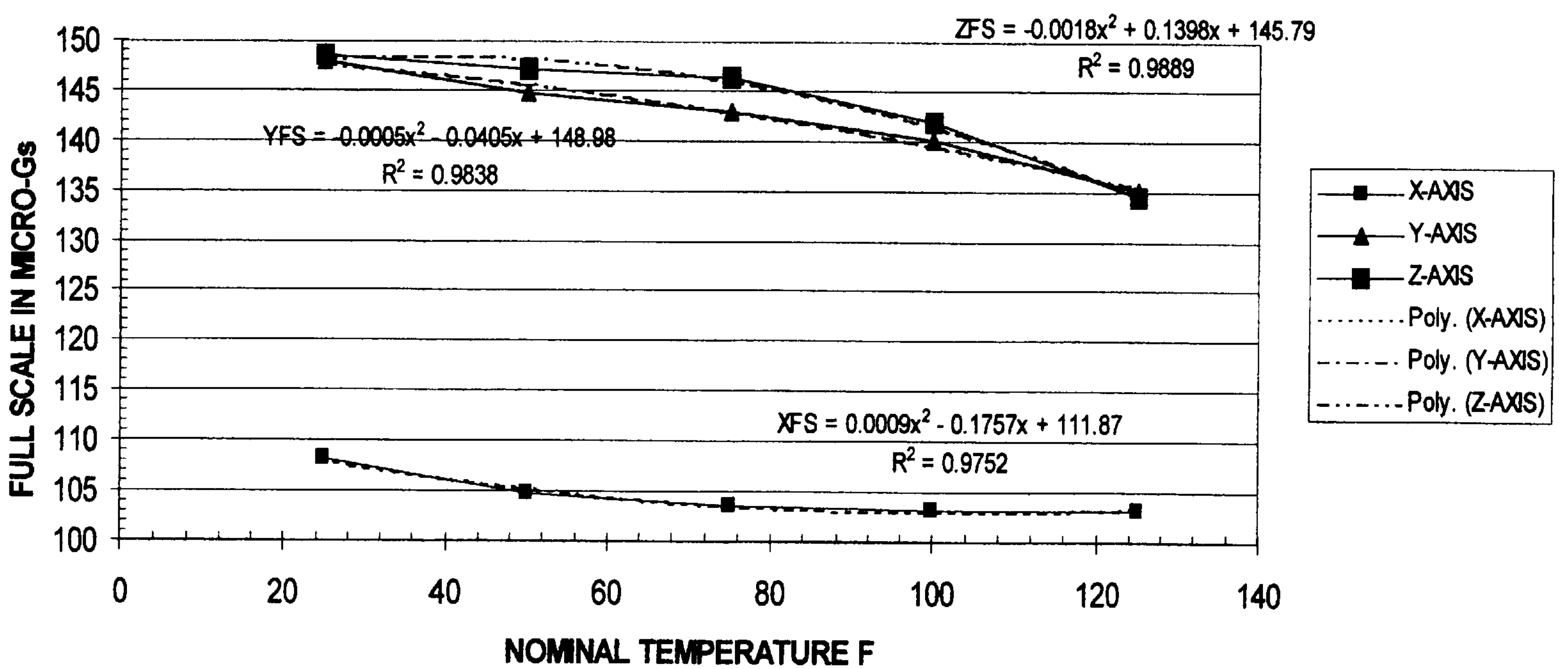
Canopus Systems

- OSS MESA Triaxial Accelerometer C-Range Scale Factors vs. Operating Temperature
- OSS MESA Triaxial Accelerometer Bias at Ambient Temperature
- OSS Anti-Aliasing (Bessel) Filter Frequency Response
- OSS X Axis ADC Noise Count Histogram
- OSS Triaxial ADC Noise Count Summary
- OSS X Axis ADC Counts vs. Time, 1 Hz. Input
- OSS X Axis Acceleration vs. 1 Hz. Sensor Output Voltage

OSS Scale Factor vs. Operating Temperature (Nom. Oper. Temp 102°F)

Canopus Systems

FULL SCALE FOR VARIOUS AXES FOR C-RANGE FOR OSS S/N 2



OSS S/N 02 Bias Measurements

Canopus Systems

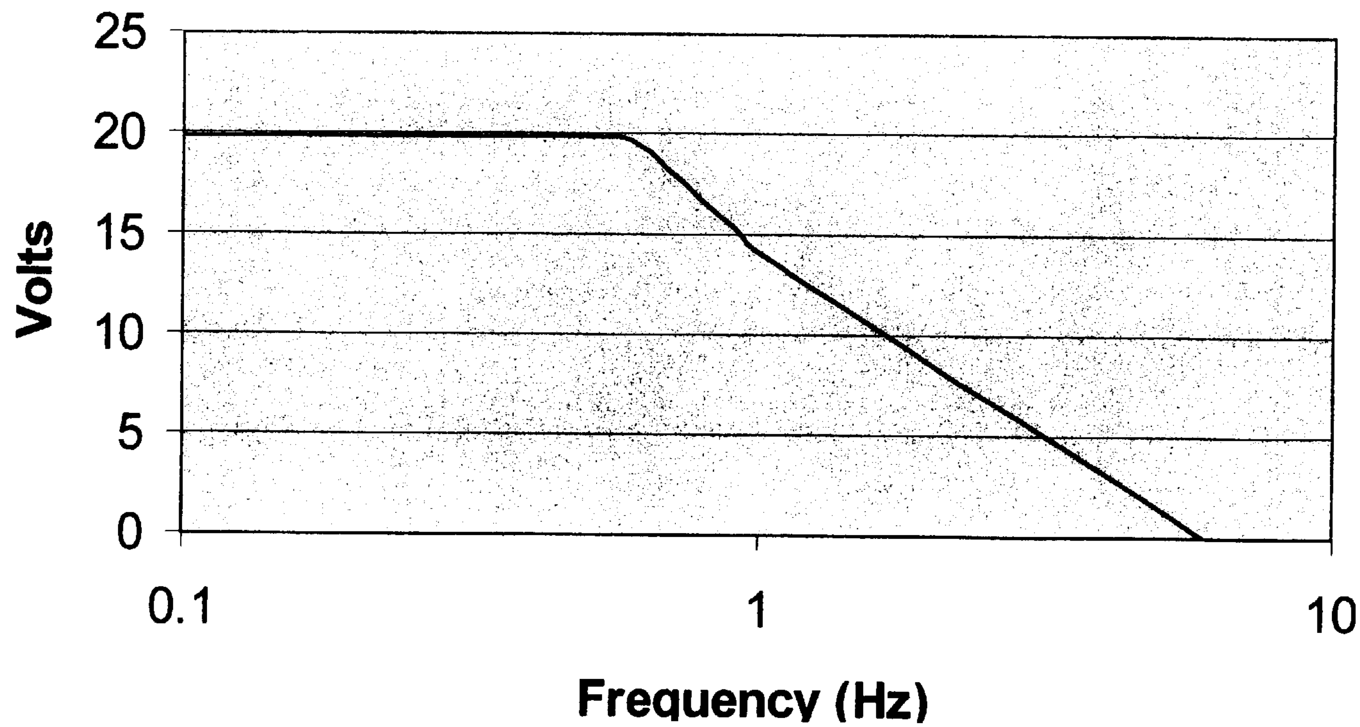
Bias Data Measurements in μg at ambient temperature on Leitz Dividing Head

Date:	9/96	7/99	8/99
X_A	+41	+12.5	+18.5
X_B	+39		
X_C	+39		
Y_A	-49	58	+5
Y_B	+175		
Y_C	+144		
Z_A	+154	-192	-207
Z_B	+12		
Z_C	+18		

OSS Bessel Filter Frequency Response

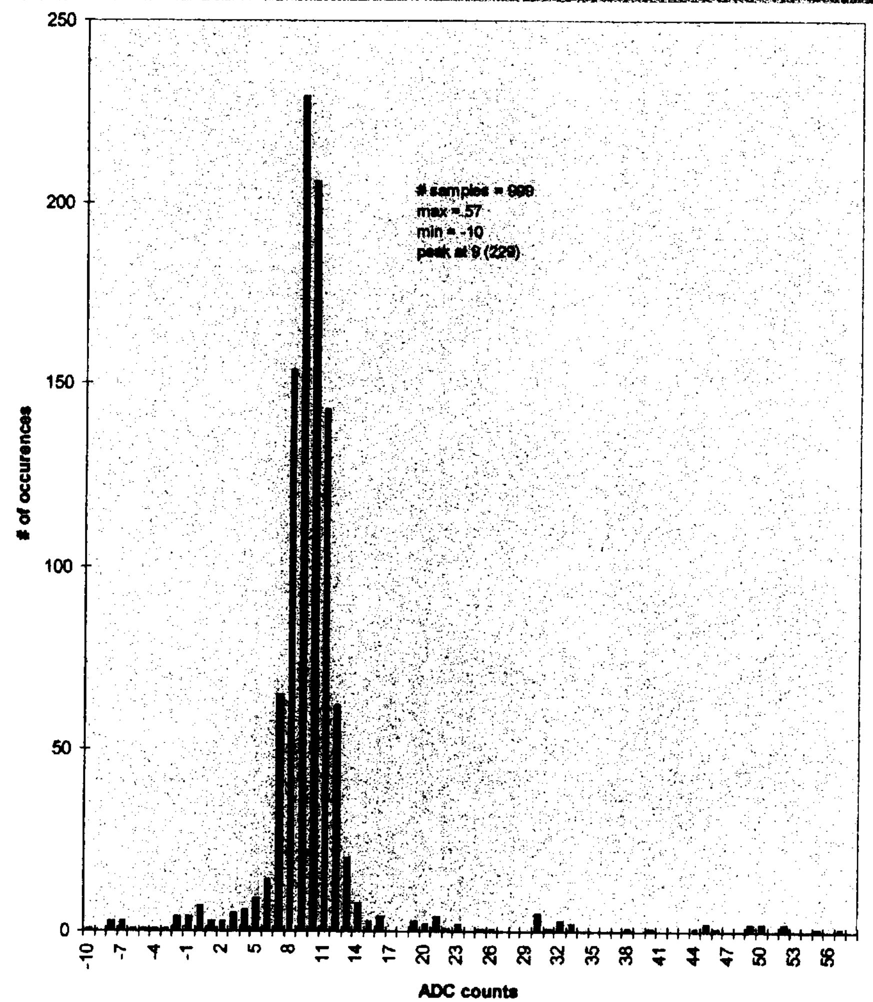
Canopus Systems

OSS LPF Output Voltage
(Vin = 20.0V, all channels)



OSS X Axis ADC Noise Count Histogram

Canopus Systems



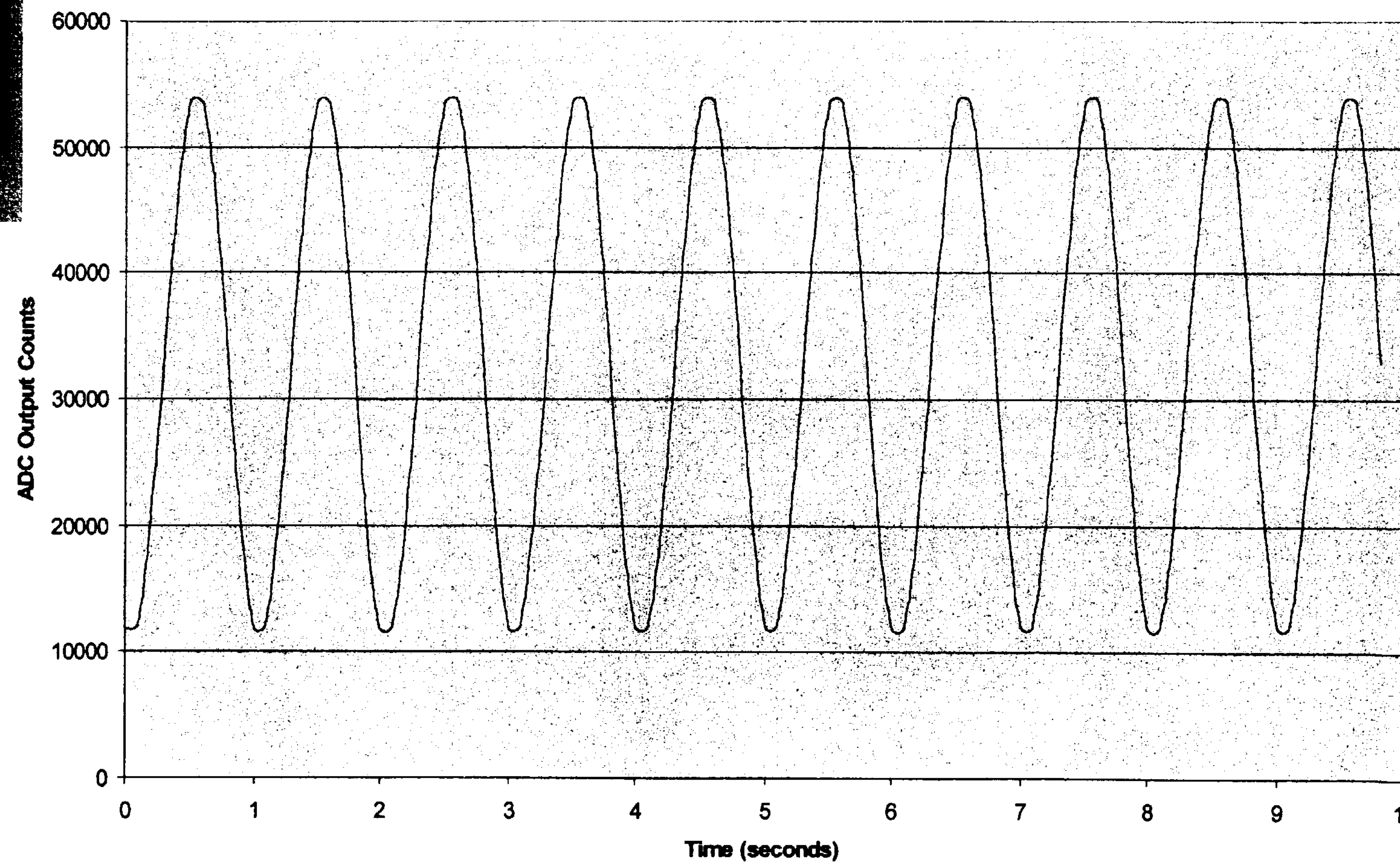
OSS ADC Noise Count Summary

Canopus Systems

MAMS System Noise Measurements			
Axis	**ADC counts**	**ADC volts**	**Acceleration (A range)**
OSS X	32763	-1.53mV	-1.53m_g
OSS Y	32764	-1.22mV	-3.05m_g
OSS Z	32764	-1.22mV	-3.05m_g

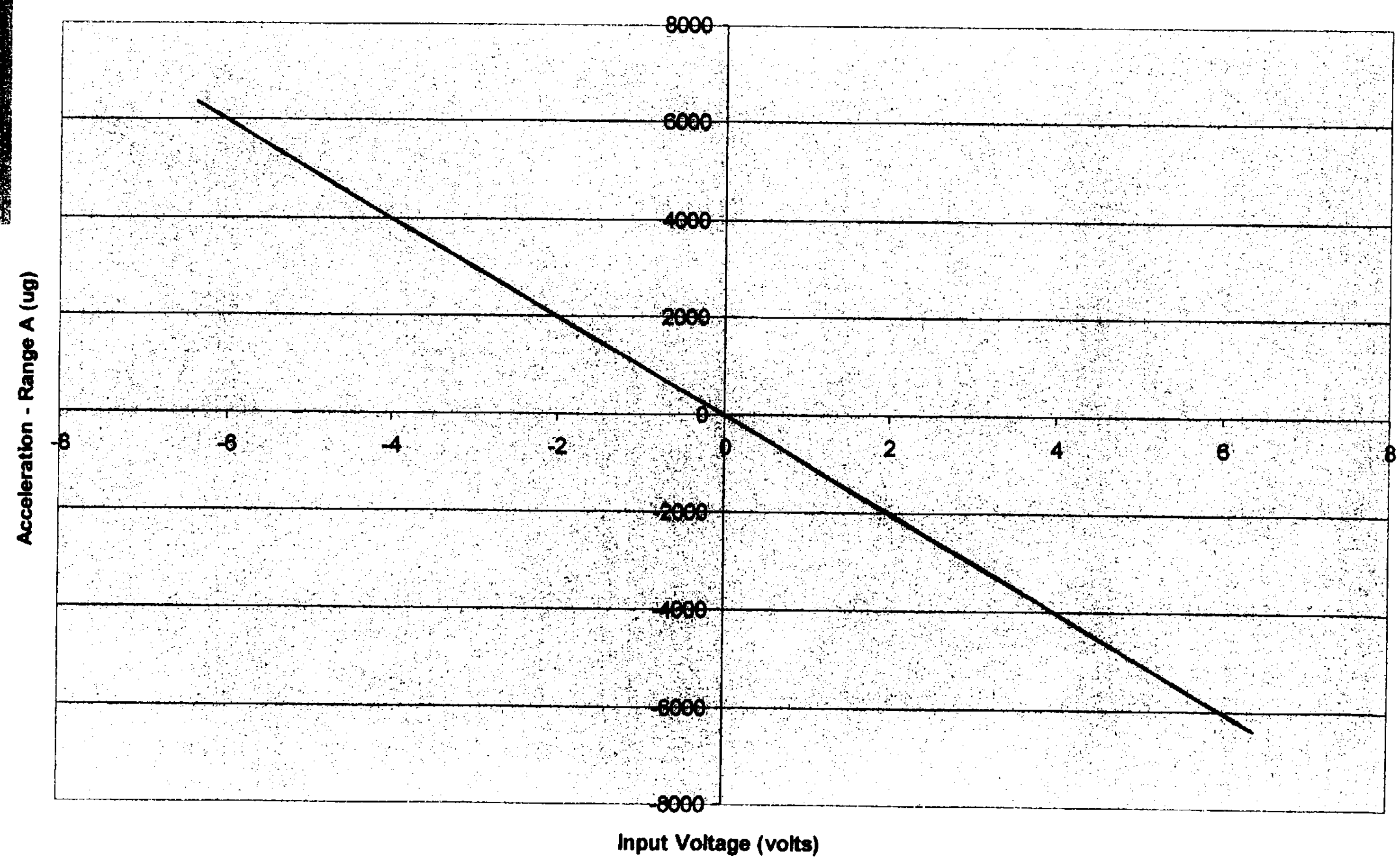
OSS X-Axis, ADC Counts vs. Time with 1 Hz Sinewave Stimulus

Canopus Systems



OSS X-Axis Acceleration vs. 1 Hz Sensor Output Voltage

Canopus Systems



OSS Cylindrical (X Axis) Sensor Misalignment Error Check

Canopus Systems

Mechanical Misalignment Error Sources

- X Input Axis Angle w.r. to OSS Base — 2.3 arc minutes (measured)
- OSS Base to BCTA Base (Gimbal Skew Tolerance) — 5.0 arc min.
- BCTA Base to DMDL Base (Subplate Flatness Spec) — 5.9 arc min
  - Allowable RSS Mechanical Error — 7.9 arc min.
- RSS Mechanical Error Limit in 1 G Field (290 μg/arc min) = 2290 μg

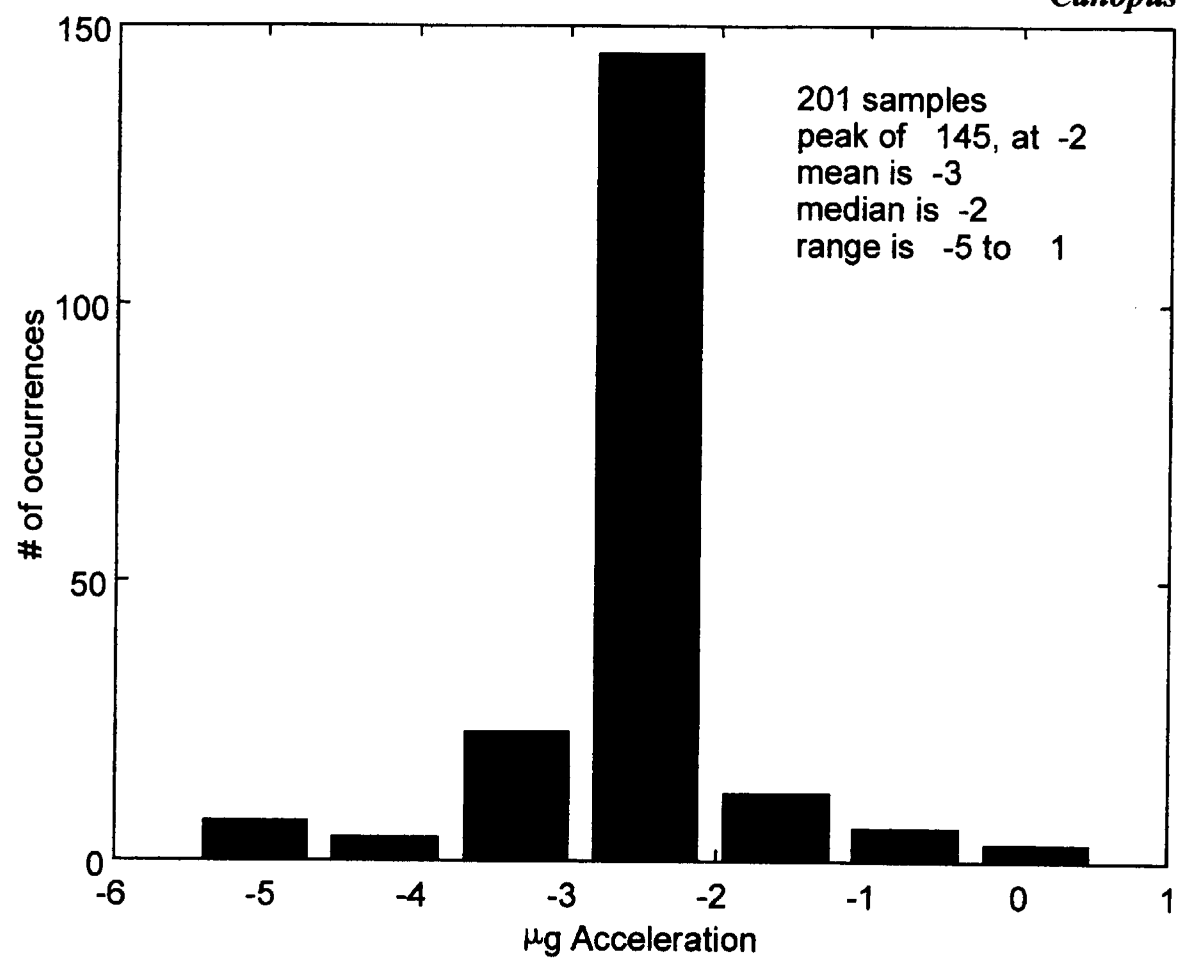
- Spot Check: 180° Rotation of X Axis with Leveled DMDL Base = 1200 μg Output Change
- Gimbal Rotation Position Check Measurements
  - OG Rotation to Hard Stop @ 273,850 microsteps (42,785 encoder cts.) = 180.027 deg.
  - IG Rotation to Hard Stop @ 71,234 microsteps (11,118 encoder cts.) = 89.999 deg.
- Data Histograms Summary:

1. X Axis Mean Acceleration, BCTA @ 0°, 0°: -3 μg
2. X Axis Mean Acceleration, BCTA @ 180°, 0°: 1197 μg
3. X Axis Mean Acceleration, BCTA @ 180°, 90°: 1122 μg

Δ O/P = 1200 μg

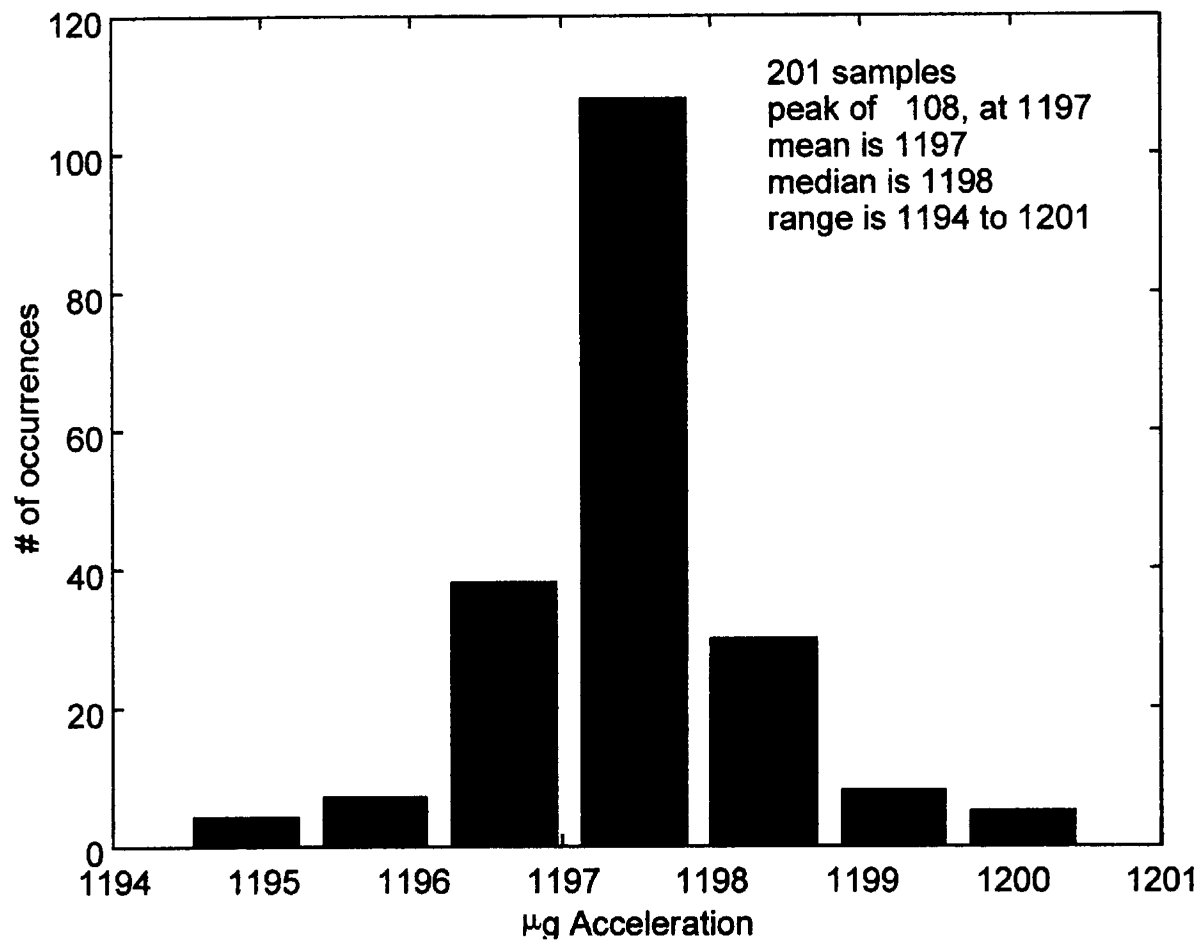
X Axis Acceleration Count Histogram, BCTA at 0°, 0°

Canopus Systems



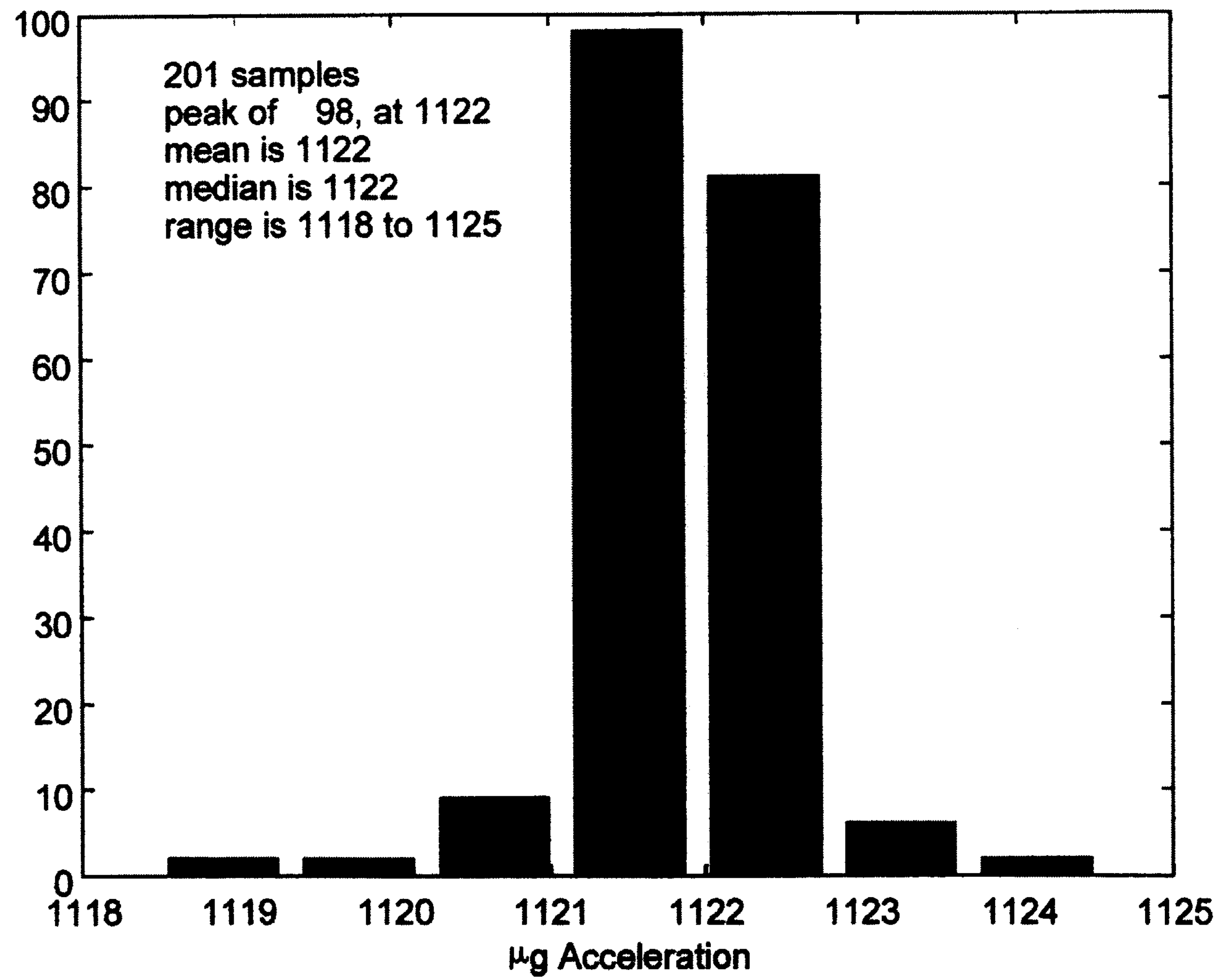
X Axis Acceleration Count Histogram, BCTA at 180°, 0°

Canopus Systems



X Axis Acceleration Count Histogram, BCTA at 180°, 90°

Canopus Systems



Vibratory Acceleration Channels Characterization Data

Canopus Systems

- HIRAP Flight Unit Photo
- HIRAP Measured Sensor Calibration Data
- HIRAP Sensor Butterworth Low Pass Filter Response
- HIRAP X Axis ADC Noise Count Histogram
- HIRAP ADC Noise Count Summary
- HIRAP X Axis ADC Counts vs. Time, 100 Hz Input
- HIRAP X Axis Acceleration vs. Sensor

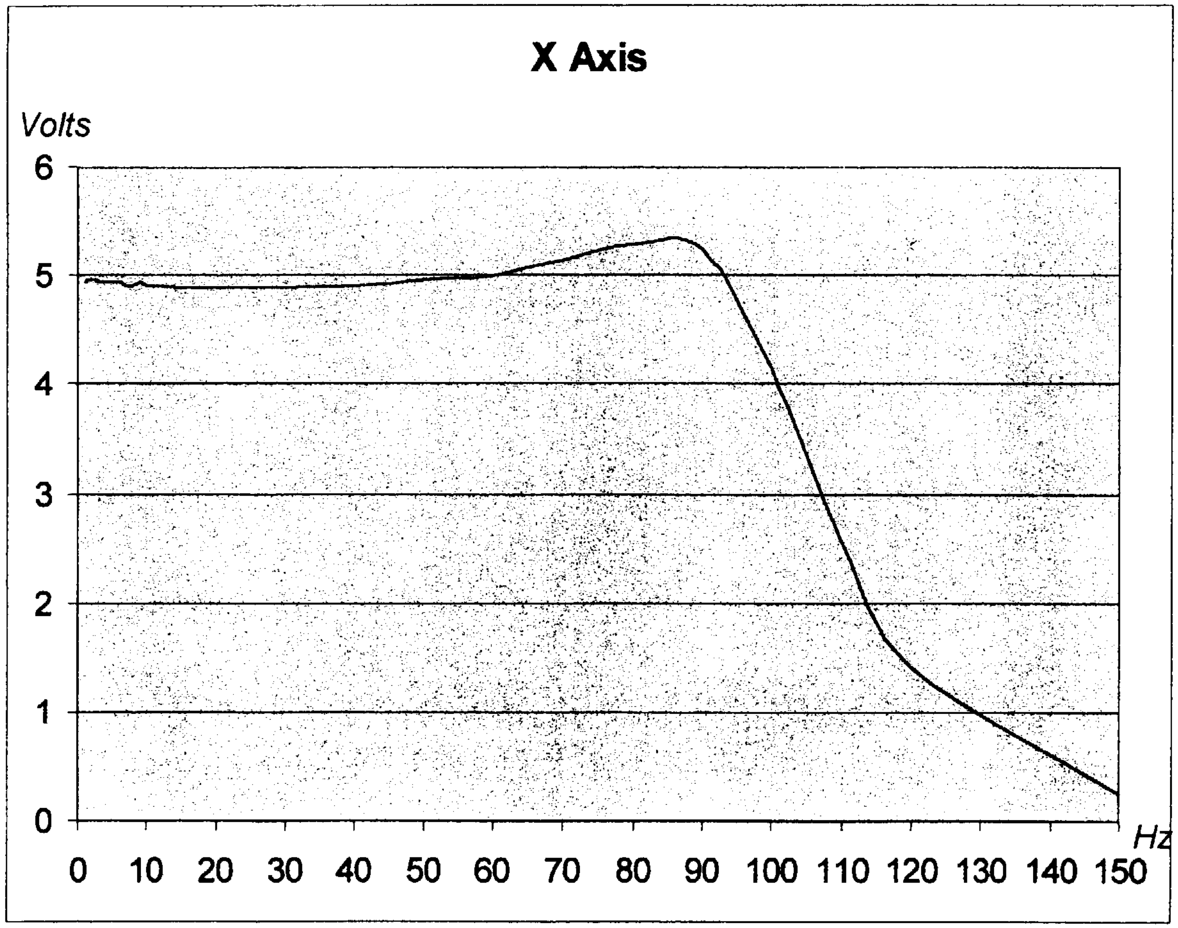
HIRAP Measured Sensor Calibration Data (per TP 400501)

Canopus Systems

s	Resolution	Scale Factor	Bias	Sensor Output Bandwidth	Anti-Aliasing Butterworth Filter Bandwidth	Filter RMS Output Noise (Random)
X	0.49 μg	-1.60167 $\frac{\text{milli-g}}{\text{volt}}$	-0.145 milli-g	159 Hz	100 Hz	113 μg
Y	0.49 μg	+1.5926 $\frac{\text{milli-g}}{\text{volt}}$	-0.639 milli-g	159 Hz	100 Hz	57 μg
Z	0.49 μg	-1.6080 $\frac{\text{milli-g}}{\text{volt}}$	-1.360 milli-g	159 Hz	100 Hz	85 μg

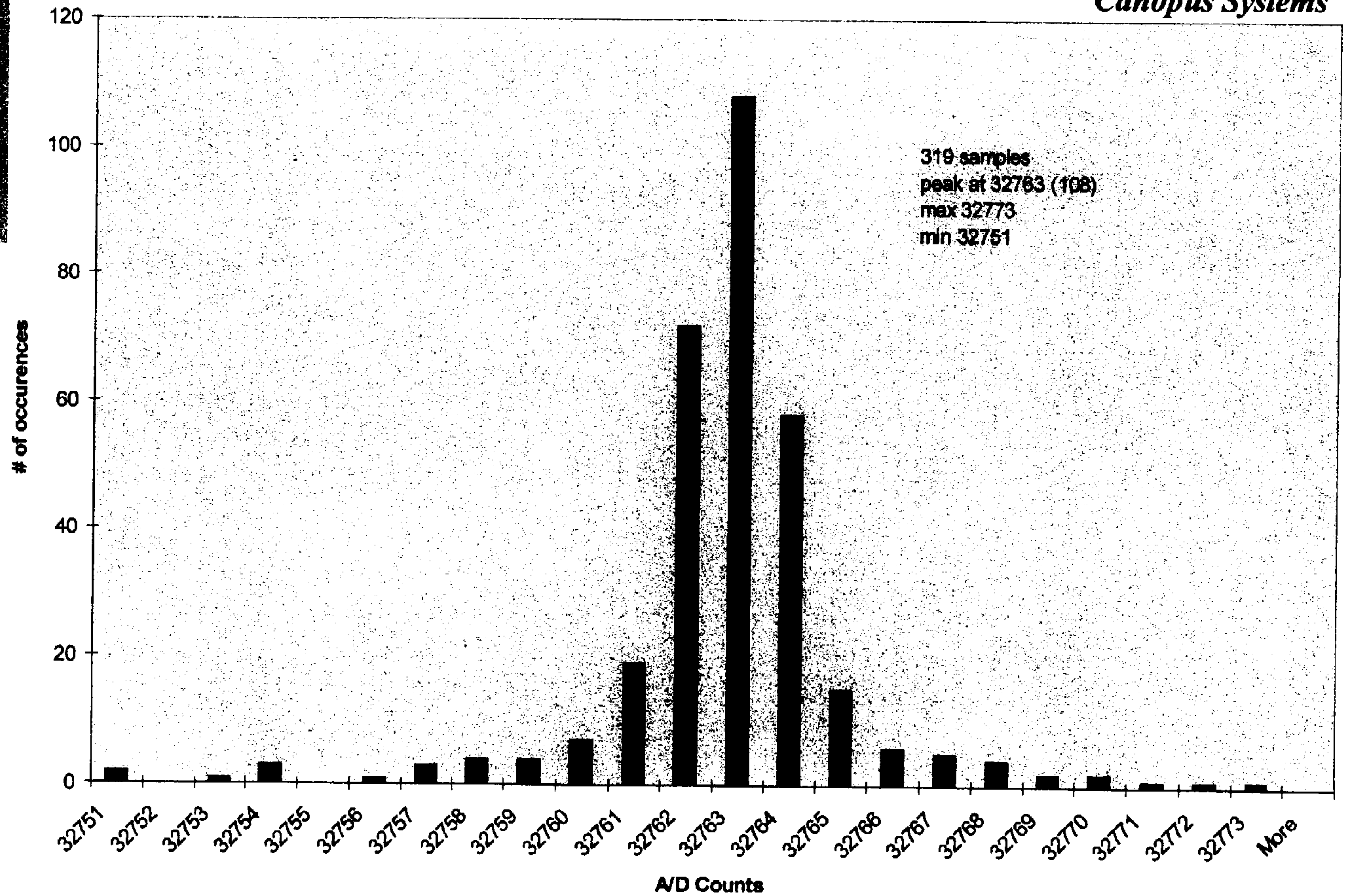
HIRAP Sensor Butterworth Low Pass Filter Frequency Response

Canopus Systems



HIRAP X Axis ADC Noise Count Histogram

Canopus Systems



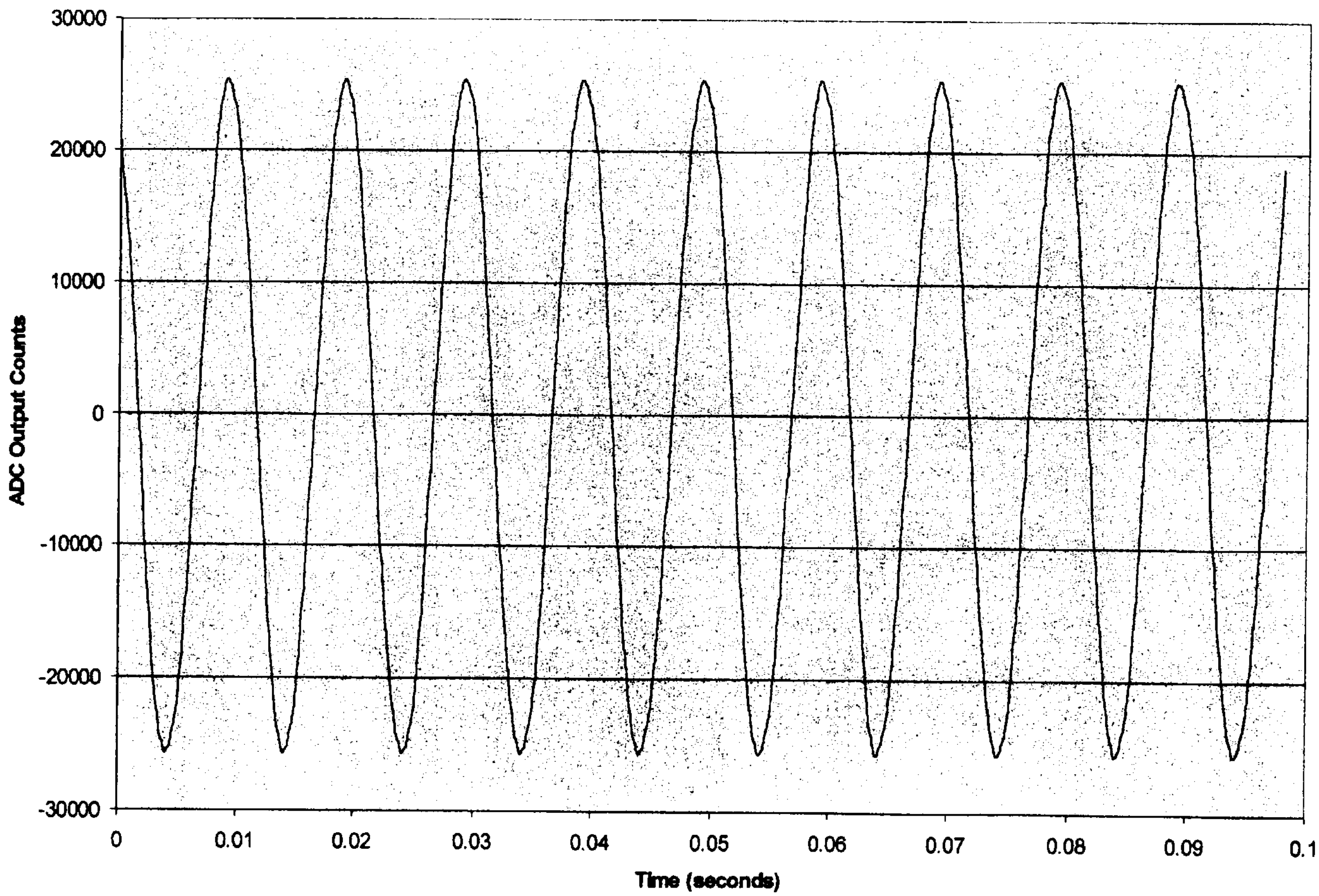
HIRAP ADC Noise Count Summary

Canopus Systems

MAMS System Noise Measurements			
Axis	**ADC counts**	**ADC volts**	**Acceleration**
HiRAP X	9	+2.7mV	+0.004mg
HiRAP Y	12 to 13	+3.7mV	+0.006mg
HiRAP Z	14 to 15	+4.3mV	+0.007mg

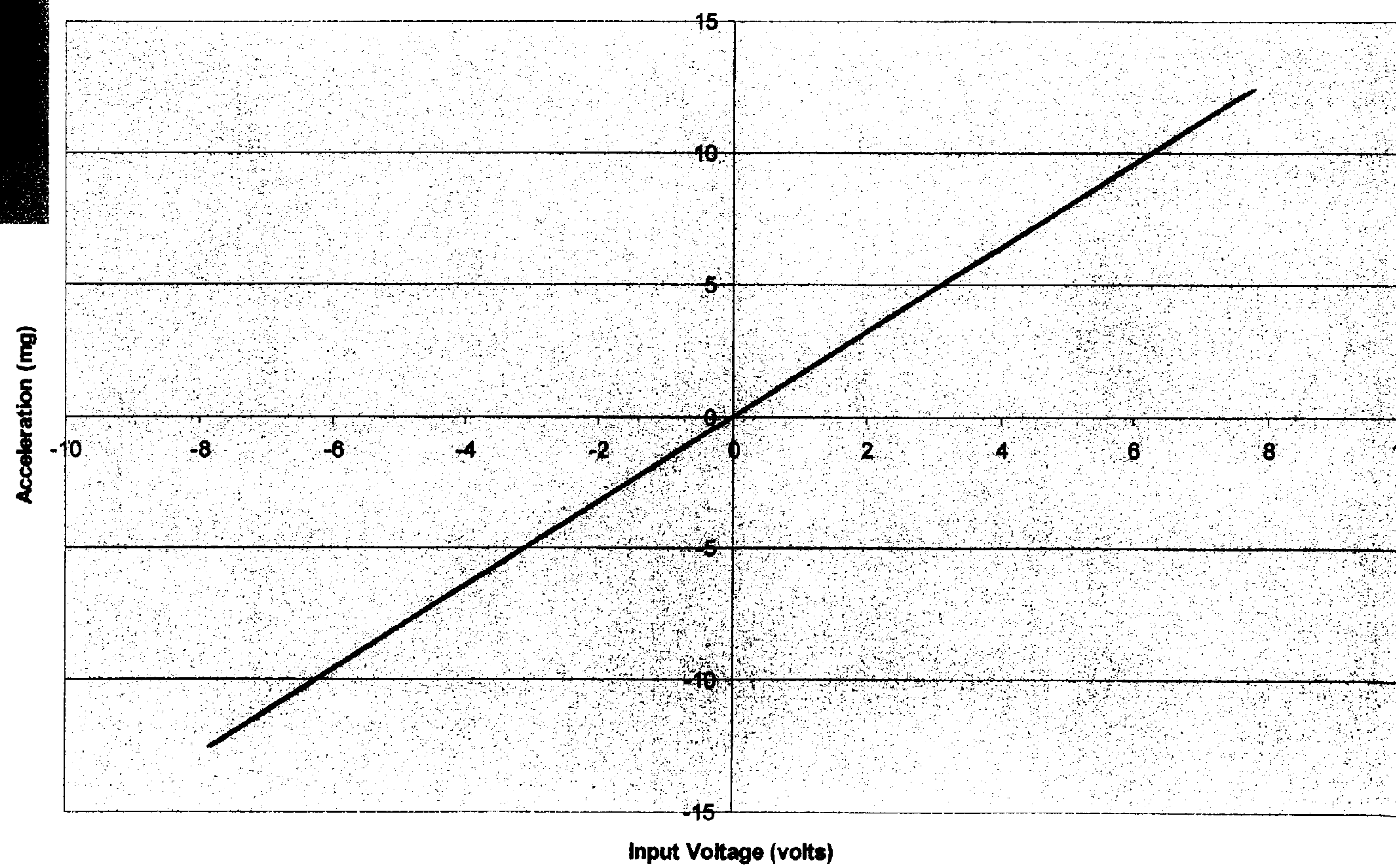
HIRAP X-axis, ADC Counts vs. Time with 100 Hz Sinewave Stimulus

Canopus Systems



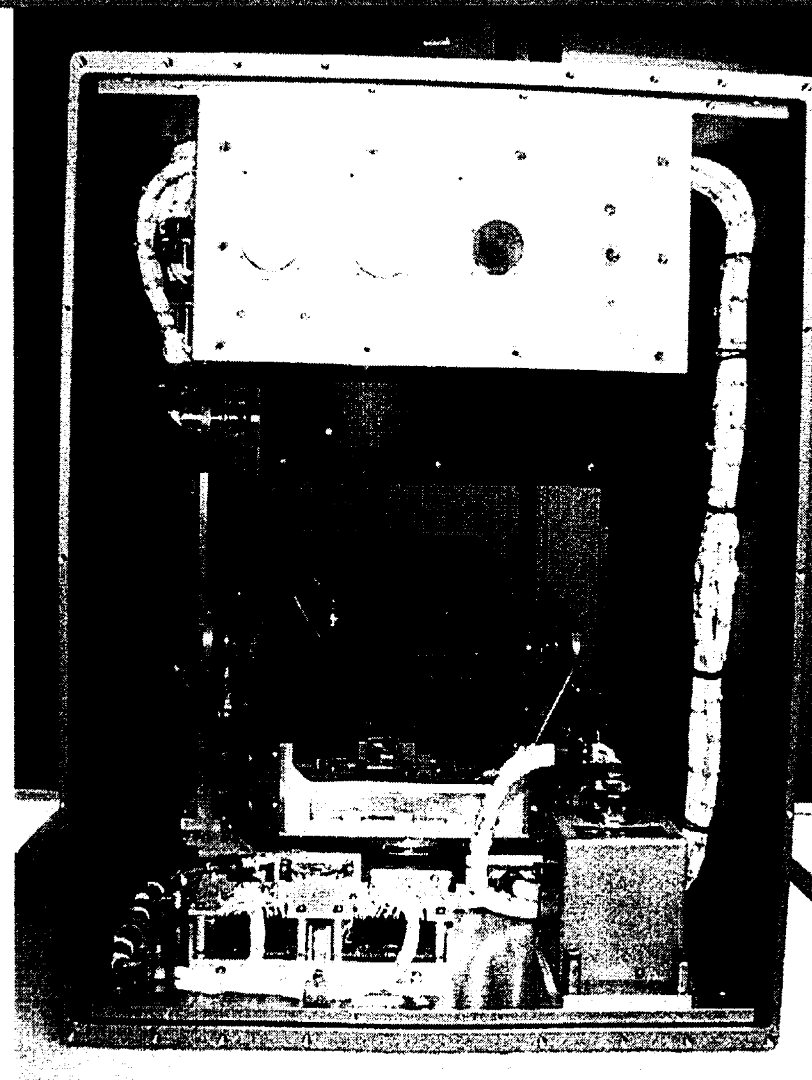
HIRAP X-Axis Acceleration vs. Sensor Output Voltage, 100 Hz Input

Canopus Systems



MAMS FRONT INSIDE VIEW

Canopus Systems



MAMS Operational Requirements

Canopus Systems

- **Nominal Unattended Operations with Minimal Ground Operator Intervention**
  - Automatic startup when power is applied via the EXPRESS RIC
    - System boots up and waits for TCP/IP Ethernet connection from the client
    - After socket connects, MAMS requests RIC time and initiates message and data transmission
  - Nominal and Default operation control provided by adaptation parameters
  - Operator command override provided to modify operational modes

MAMS Data Collection Rates

Canopus Systems

- OARE Acceleration Data
  - 3 axes at 10 samples per second
- HiRAP Acceleration Data
  - 3 axes at 1000 samples per second
- Payload Health and Status Data at 1 Hz
- General Housekeeping and Time Stamp Status sent at Science Data Rates

MAMS Required Communication Functions

Canopus Systems

- Ethernet per Payload/RIC Interface, IDD Table 11-II
  - Complies with ANSI/IEEE-STD-802.3 and TCP/IP, v4
- Commands routed from UOF to RIC to MAMS
- Data transmitted from MAMS to RIC to UOF
- Health and Status Data to RIC per IDD Table 11-XXIII
- Adaptation Parameter Upload Capability

MAMS Messages and Telemetry Data Type Definitions

Canopus Systems

MAMS Message Type	Description and EXPRESS Secondary Header Telemetry Data Type *	Approximate Required Ethernet Trans. Rate including ER headers (bits per second)
1. Payload Health/Status Message to ISS	Required MAMS Health and Status Message sent every second. None.	304 bps, sent every second
2. Error & State Message (Text **Message**)	Text Messages which describe command responses, operating errors, **warnings** and **diagnostics**. **Data type 2.**	0.1 bps
3. Status/Housekeeping	Housekeeping, Time Correlation, and Status. **Data type 4.**	0.8 bps
4. OSS Near-Real-Time Acceleration Measurements	OSS Acceleration Measurements at 10 samples per second plus ancillary data, either filtered or unfiltered. **Data type 3.**	543 bps
5. OSS Stored Acceleration Measurements	OSS Acceleration Measurements and ancillary data--stored Near-Real-Time data, either filtered or unfiltered. **Data type 5.**	543 bps, For dump, rate can be controlled from 1 to 200 kbps
6. HiRAP Raw Acceleration Measurements	HiRAP Acceleration Measurements. **Data type 1.**	50 kbps
7. MAMS Parameter List **Series of text messages**	Current Operational Adaptation Parameters. **Data type 2.**	not applicable

- *Message Types 2-7 transmission can be modified via commands (and adaptation parameters)*

* *Express Secondary Header Telemetry Data Type per IDD Table 11-VI*

MAMS Health and Status Message

Canopus Systems

The MAMS Health and Status Message (not including the **synch word, nor the EXPRESS Primary Header)**.

ECW Word (Reserved Word 1)	
HiRAP X Temperature	HiRAP Y Temperature
HiRAP Z Temperature	BCTA Current
OSS Instrument Temperature(low byte)	OSS Instrument Temp (high byte)
OSS Base Temperature (low byte)	OSS Base Temperature(high byte)
MPCS1 Temperature (low byte)	MPCS1 Temperature (high byte)
MOIS Temperature (low byte)	MOIS Temperature (high byte)
Power Supply Temperature	System Current
Outer Gimbal Temperature	**Front Panel Temperature**

MAMS Command Types

Canopus Systems

	DATA TRANSMISSION COMMANDS		DATA THROTTLING COMMAND		FAN CONTROL COMMANDS
1a	Send Real-Time OSS Data to UOF	8	Set Maximum Data Transmission Rate from Stored Acceleration Buffer	**20a**	**Turn Fan ON**
1b	Do Not Send Real-Time OSS Data		**BIAS CALIBRATION COMMANDS**	**20b**	**Turn Fan OFF**
2a	Store Real-Time OSS Data				
2b	Do not Store Real-Time OSS Data	9	Reset NUMBER_BIAS_RANGES Parameter (This parameter controls the bias calibration sequence after one has been requested.)		**BCTA POSITION COMMANDS**
3a	Send Stored Real-Time OSS Data	10	Reset BIAS_PERIOD Parameter (in minutes) (This parameter controls when a bias calibration is scheduled)	**21a**	**Move Inner Gimbal to Std. Pos.**
3b	Stop Sending Stored Real-Time OSS Data		**OSS DATA SELECTION COMMANDS**	**21b**	**Move Outer Gimbal to Opp. Pos.**
4a	Send HiRAP Data	11a	Select OSS AFSD acceleration data for use	**21c**	**Move Inner Gimbal to Opp. Pos.**
4b	Do Not Send HiRAP Data	11b	Select OSS Raw (unfiltered) acceleration data for use.	**21d**	**Move Outer Gimbal to Std. Pos.**
5	Reset Status_Housekeeping_Period. (in minutes) (This parameter controls when a Status/Housekeeping Packet (SHP) is sent as Backup)	12	Set Minimum OSS Range (Axis, Range)		
6	Set Error/Status (Text Message) Transmission State (on/off and level); Messages will not be buffered if not sent.		**GLOBAL RESET COMMAND**	22	Create New Adaptation Parameter File
7	Send Adaptation Parameter List	13	Reset MPCS		

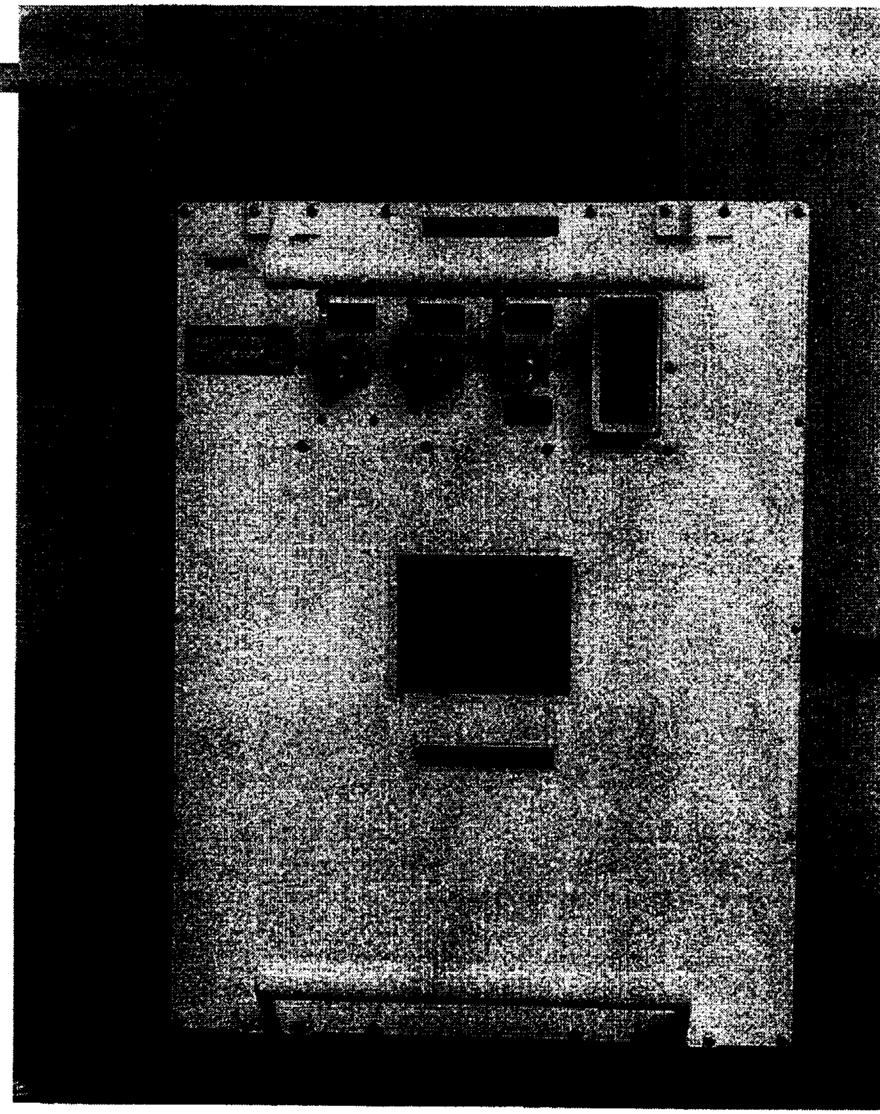
Additional MAMS Functions

Canopus Systems

- Ethernet connection/reconnection
- Time Stamping
- OSS ranging on each accelerometer axis
- Proofmass capture in event of Loss of constrainment
- Bias Calibration and Bias Calibration Table Control (Includes Backup BCTA Control Mode via Adaptation Parameter)
- Message Formatting

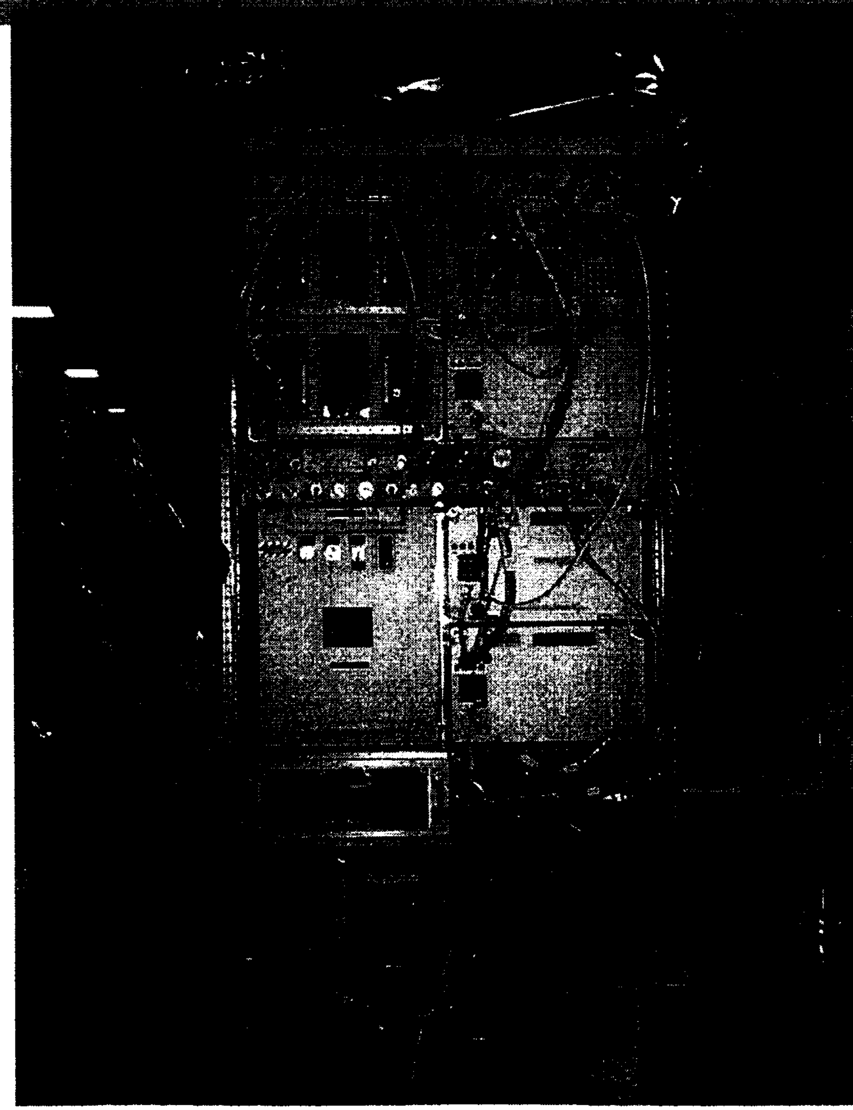
MAMS FLIGHT CONFIGURATION

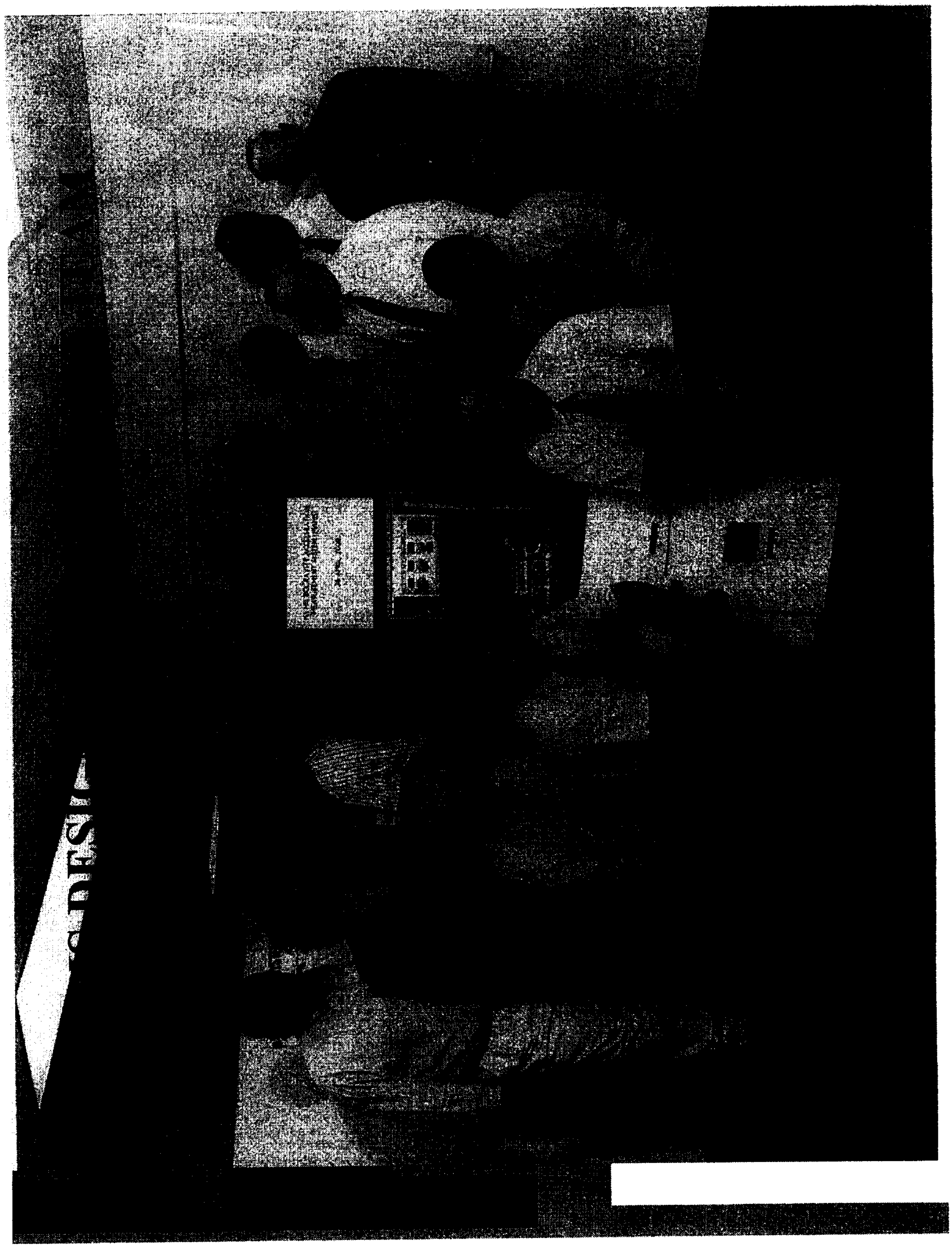
Canopus Systems



MAMS Installed in ER#1

Canopus Systems





-4/1?

200101971

5/1256

20P5

Paper Number: 3

SAMS-FF: One system, many missions

Thomas Kacpura
ZIN Technologies
Brook Park, Ohio

The SAMS-FF system was developed as a flexible, modular system. The advantages of this configuration are that the basic platform can easily be adapted for specific mission requirements without having to redesign the complete system each time. Mission-specific hardware has designed and operated for a variety of different missions, from ground-based platforms including drop towers and reduced gravity parabolic aircraft, to sounding rockets and the space shuttle. This presentation will describe the hardware and mission results of several of the missions supported by SAMS-FF in the last year.

SAMS-FF:
One System, Many Missions

Prepared by:

Tom Kacpura

Ron Sicker

Dale Mortensen

19th International MicroGravity Measurements Group (MGMG) Meeting

Tuesday, July 11, 2000

Introduction

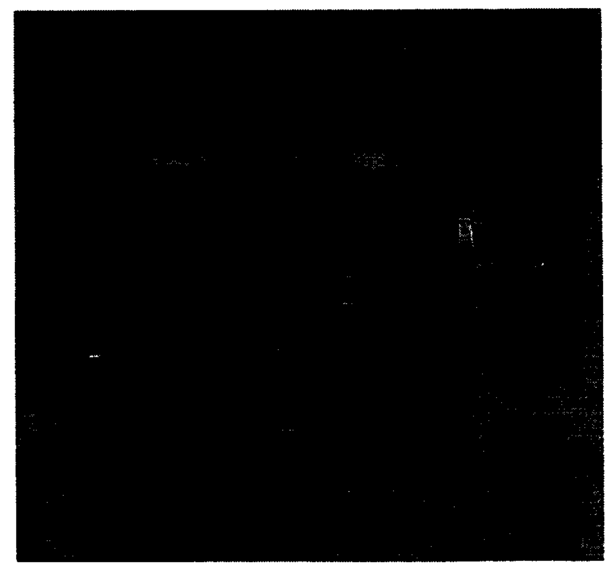
- The SAMS-FF system was developed as a flexible, modular system. The basic platform can be easily adapted for specific mission requirements without having to redesign the entire system.
- The SAMS-FF system has been configured and operated for a variety of different missions, from ground-based platforms including drop towers and reduced gravity parabolic aircraft, to sounding rockets and the Space Shuttle.
- This presentation describes the hardware configurations and mission results of SAMS-FF over the last year.

Component Specifications

Sensor	*TSH*	*CDU*	*FOG*
Description	3 QA-3100 Accelerometers (Allied Signal)	PC/104 Cards: CPU, I/O, Serial, Data Storage (solid state or rotational)	Fiber Optic Gyroscope (Fibersense)
Measured Quantity	Acceleration		Roll Rate
Dimensions (L x W x H)	2.9”x 2.9”x 2.8”	5.3”x5.3”x5”	3.8”x 4.4”x3.0” Gyro 4.8”x5.0”x2.2” Intf.
Weight, lbs.	1.1	5	3.75
Power (W)	1.6	10	7 nom. (temp dep)
Interface	RS-422	RS-232 (to GSE) RS-422 (to TM)	RS-232
Bandwidth	dc to 200 Hz Selectable		10 Hz Sampling
Maximum Scale	1.25g		190°/sec
Resolution	0.1 ug (sensor spec)		0.1 arc-sec (LSB)

Standalone TSH

- The TSH can be used "stand-alone" (without SAMS-FF CDU)
  - Power: +/- 15VDC, 1.65W
  - Digital data output and control through standard RS-422 serial interface
- Most payloads have a control computer
  - Connect TSH, add power, and install software
  - Easy to use where space is a premium
  - Easy to synchronize data with other payload sensors
- Missions Supported
  - FCF
  - ugSEG (KC-135 flight)



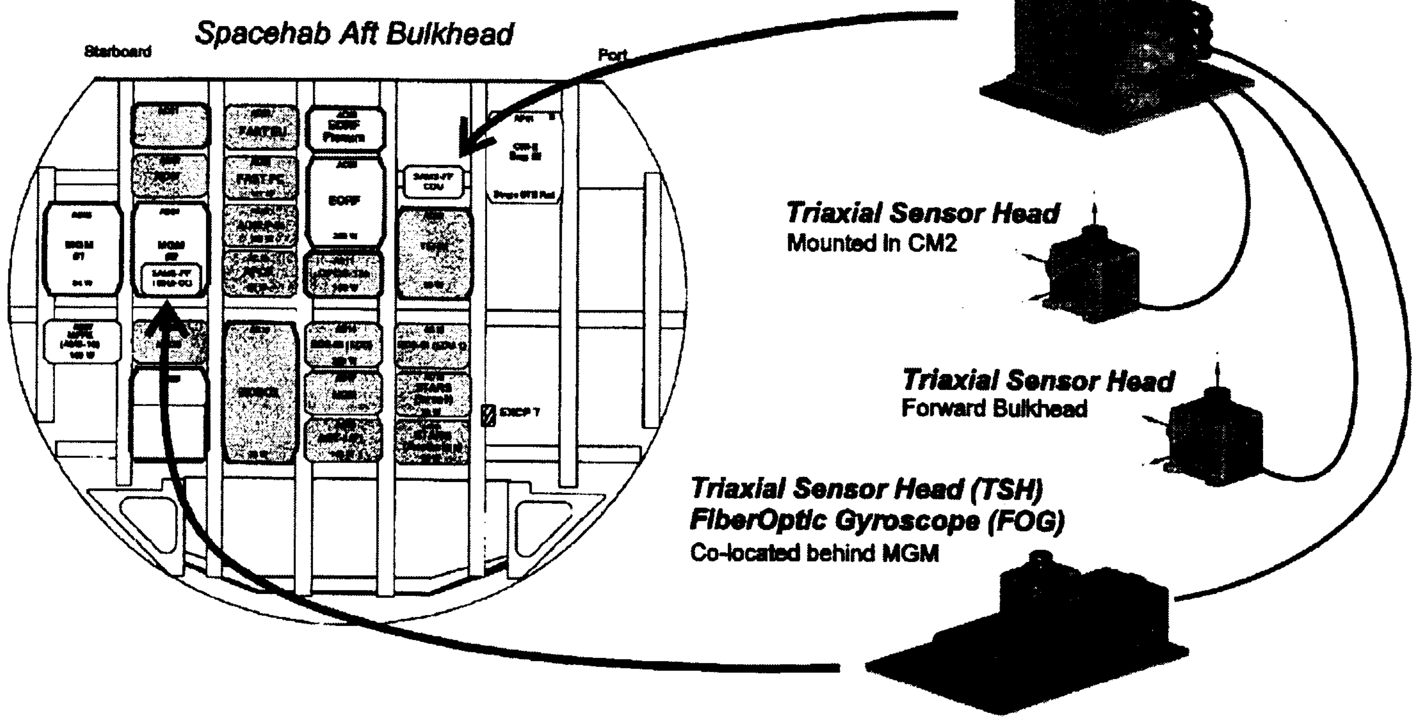
11 SAMS-FF TSHs are being built for integration in the GRC Fluids and Combustion Facility that is being designed and fabricated for flight on the International Space Station.

SAMS-FF on STS-107

Shuttle Mission (6/01)

Highlights:

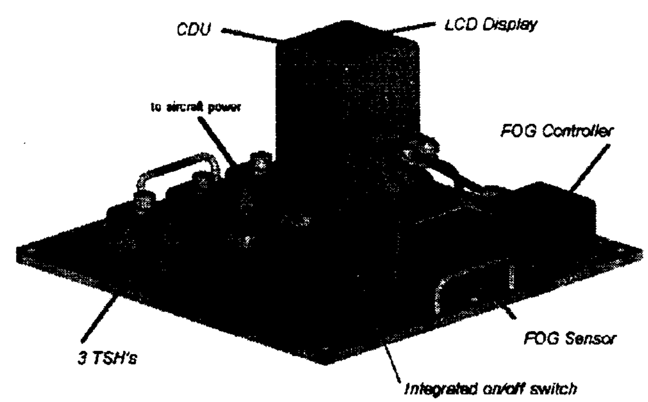
- **Acceleration and Roll-Rate measurements**
- **Downlink for real-time data display of selected sensors**

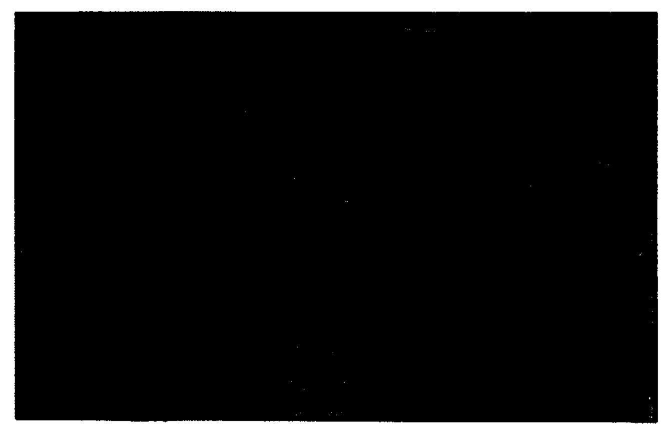


SAMS-FF STS-107 Checkout Flight on the KC-135

- Flew system on the KC-135 parabolic aircraft to:
  - Verify operation in low-g setting
  - Exercise system from hardware integration and operation through data processing
- Flew all components of the STS-107 mission:
  - CDU
  - 3 TSHs
  - FOG

SAMS-FF KC-135 STS-107 System Checkout Configuration - A

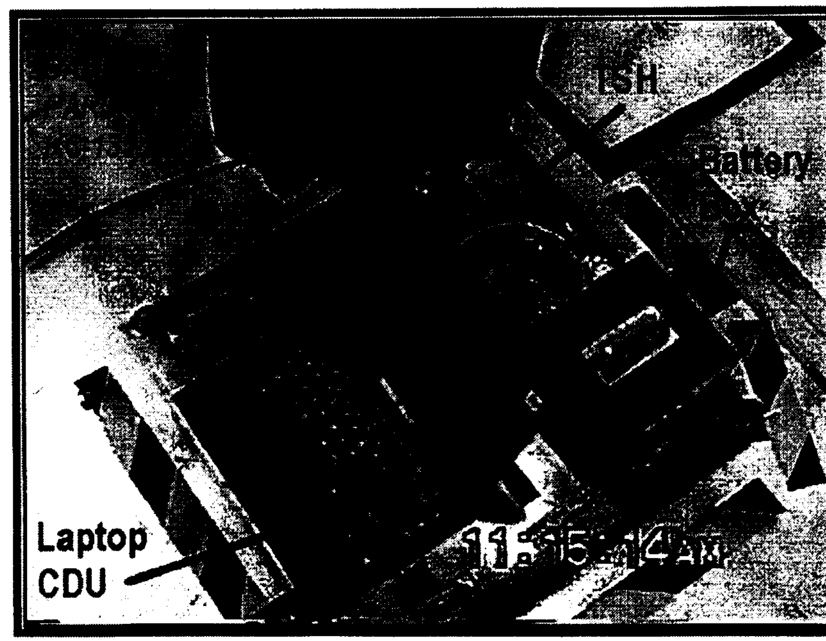




SAMS-FF STS-107 System Mounted in KC-135

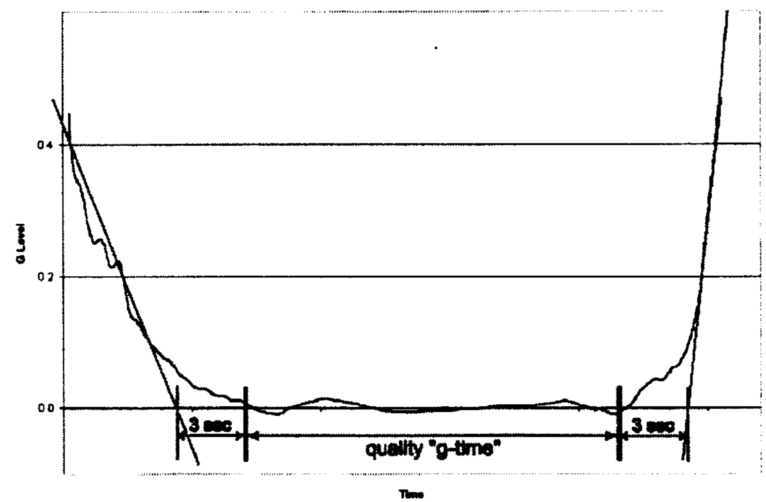
PARS:
Parabolic Aircraft Rating System

- Need:
  - A concise and timely way of informing both experimenters and crew of the "quality" of parabolas flown
- SAMS-FF Configuration
  - 1 TSH
  - 1 CDU (laptop PC)
  - Battery Box (power to TSH)
  - 50 Hz sampling rate *(BW (-3dB)=13.1 Hz)*
  - <u>Intelligent</u> data gathering
    - only records data below 0.7g
    - makes parabola identification easy
    - focuses on conditions of most interest



PARS:
Parabolic Aircraft Rating System

- A 1→10 scale rating based on statistical analysis by KC-135 personnel of historical g-data.
- SAMS-FF constantly monitors the g-environment.
  - Records each parabola in separate data files
  - Computes rating immediately following each parabola
  - Rating displayed on screen and recorded in file for later printing
  - Individual parabola data can be provided post flight upon request for further evaluation



❶ find 0.4 and 0.2 crossing points

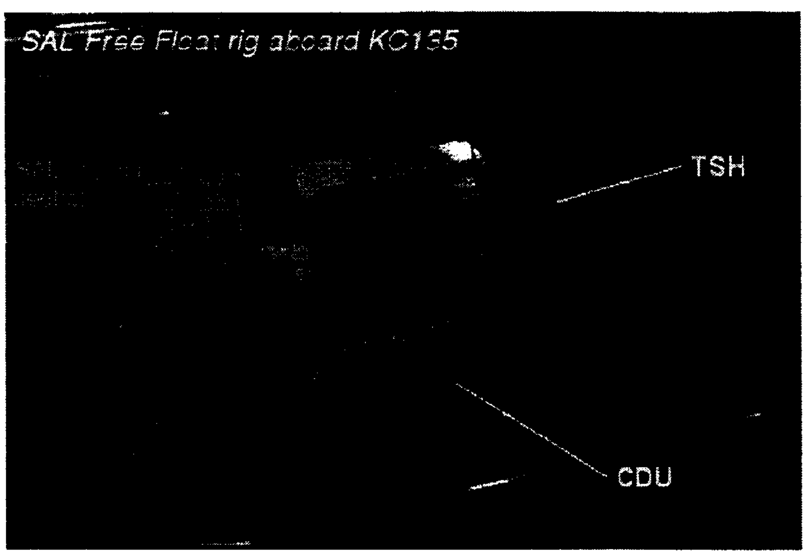
❷ determine 0-intercept points of these lines

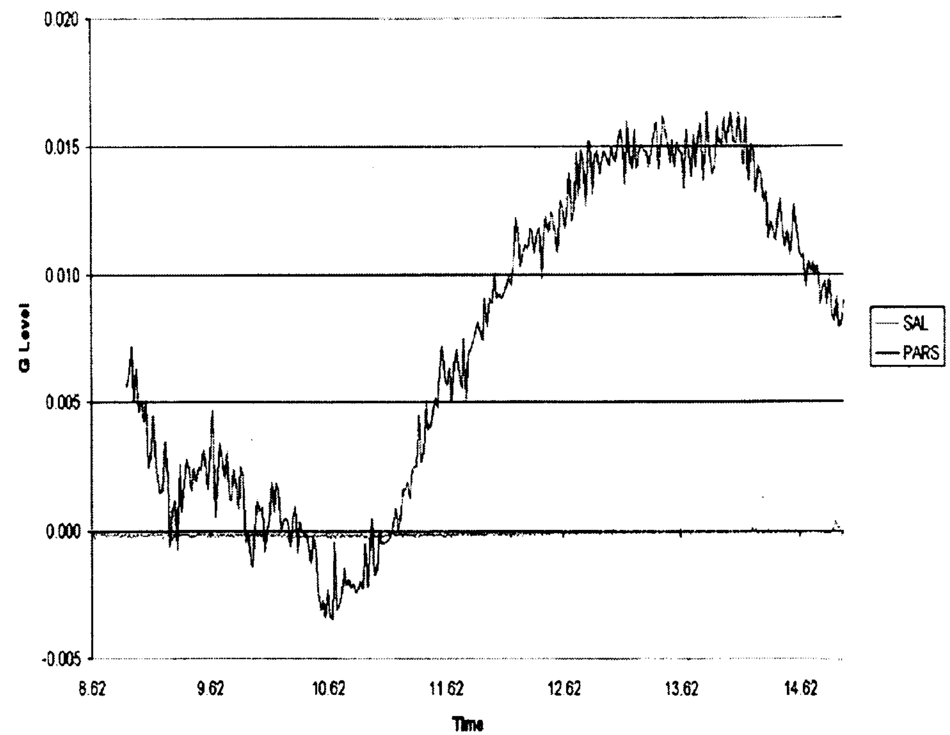
❸ offset by 3 seconds to avoid entry/exit noise

❹ determine rating based on g RMS over the quality period.

Supporting the Spread Across Liquids (SAL) Experiment

- KC-135 Flights:
- *4/26-30/99 & 6/14-18/99*
- A free-float rig with one TSH and a CDU

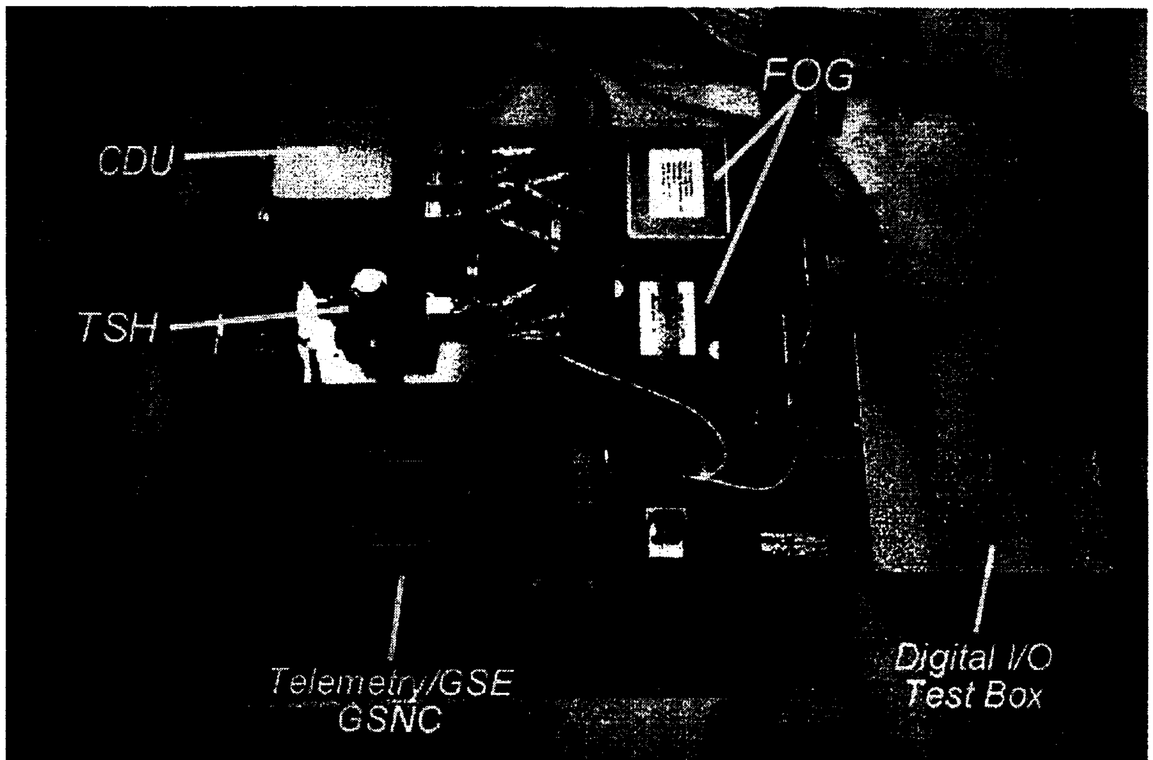




SAL freefloat vs. PARS boltdown quality low-g time Parabola #1 4/30/99

KC-135 Platforms in Support of Microscale Heaters

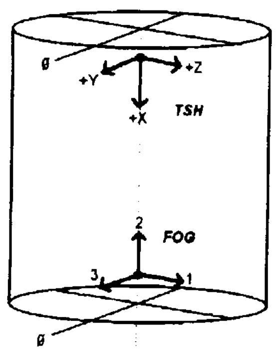
- Reflight of hardware used on 41.020

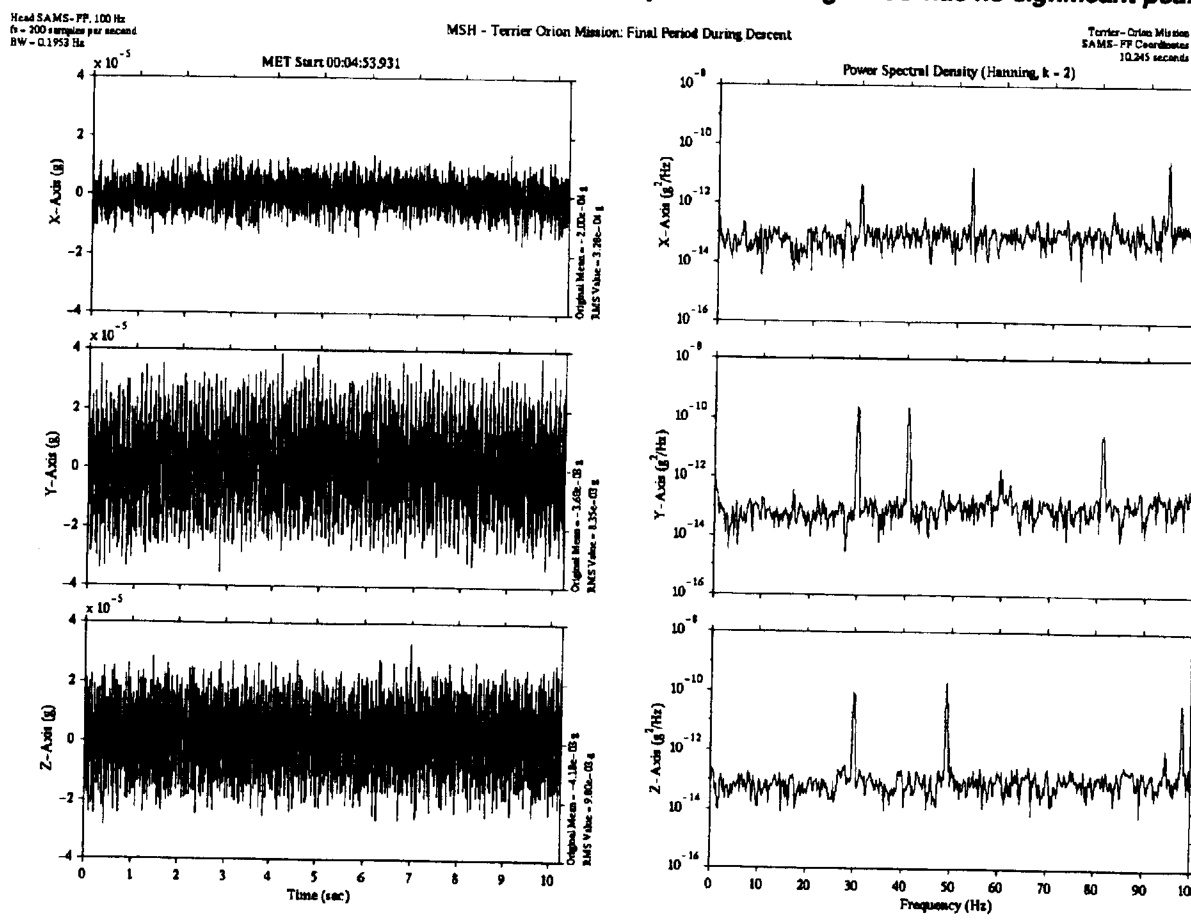


Terrier-Orion Sounding Rocket Mission Results-TSH

General: ***The SAMS-FF sensors consisted of a TSH and a FOG. Total time for TSH acceleration measurements was 277seconds.***

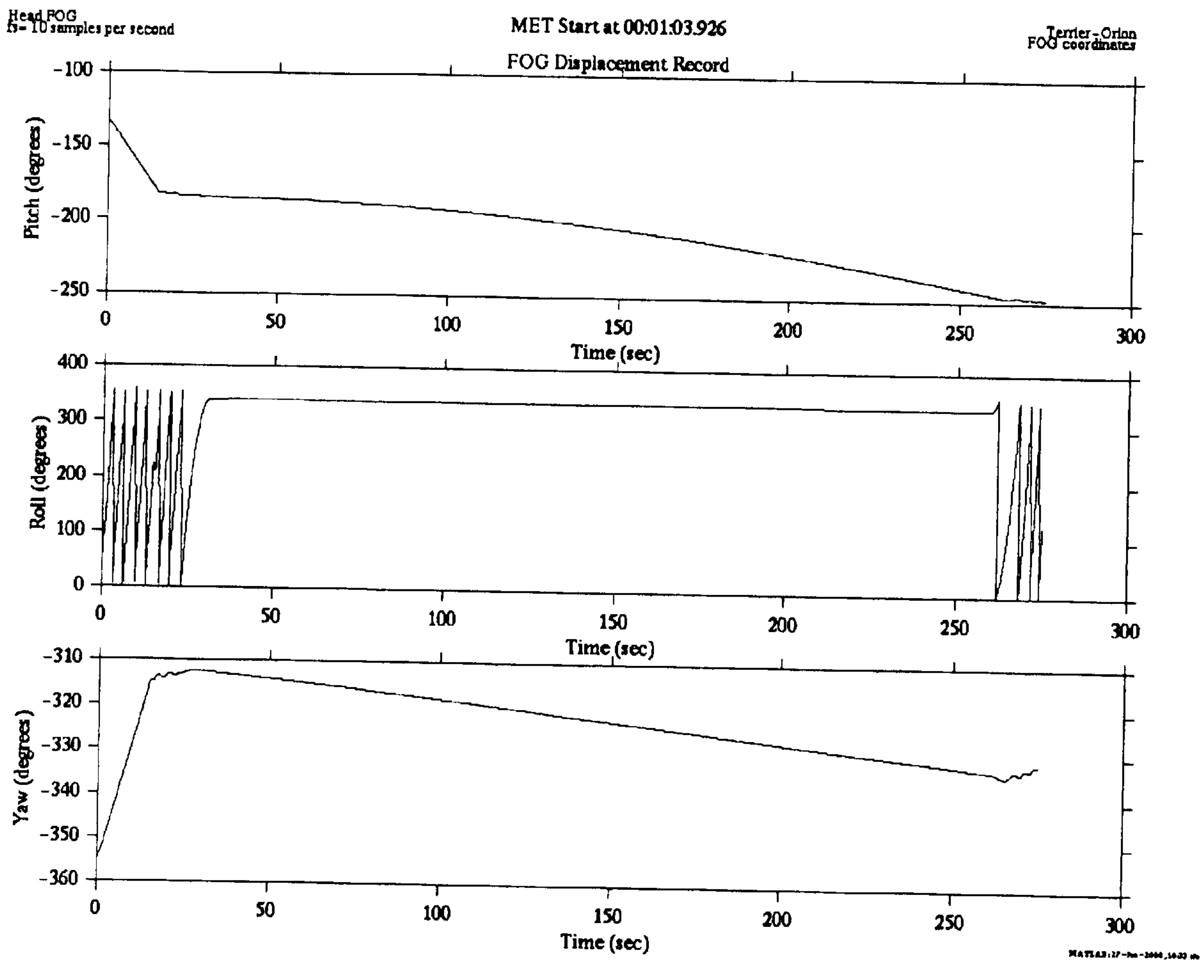
TSH Data: ***Data has appearance of noise floor data, with maximum amplitude of 2.7 ug . PSD has no significant peaks, and noise floor is near 10^{-14}.***

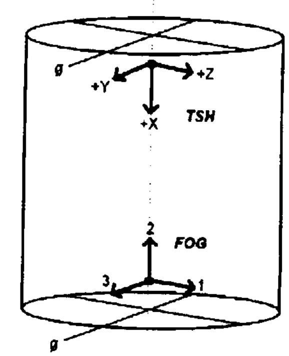




Terrier-Orion Sounding Rocket Mission Results-FOG

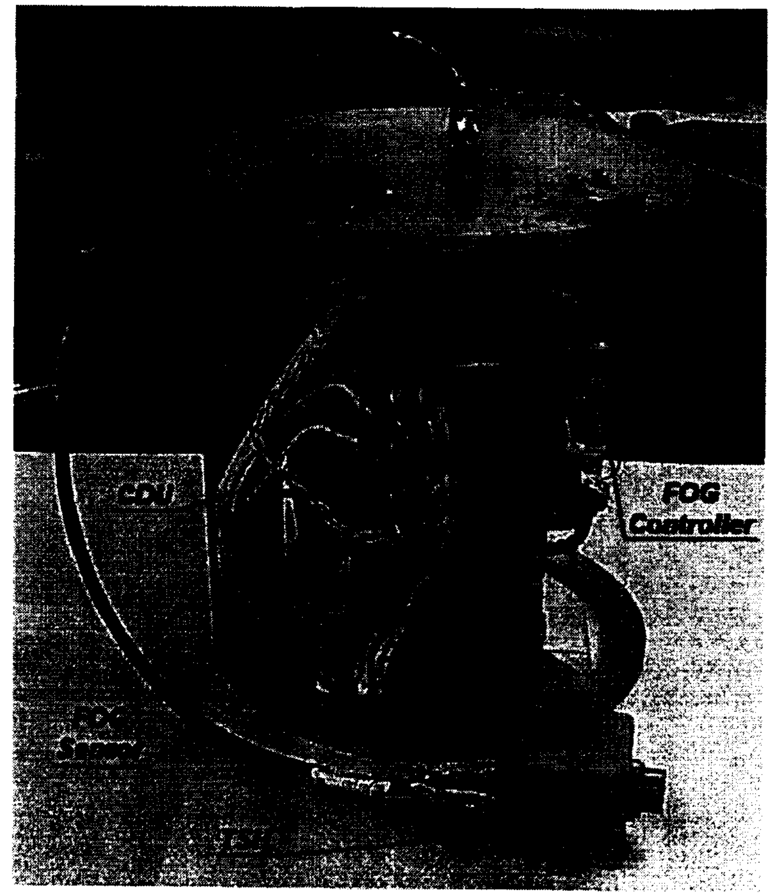
Approximately 16 degrees of roll were experienced during the ug portion of the flight.





Terrier-Orion Sounding Rocket (Flight 41.020)

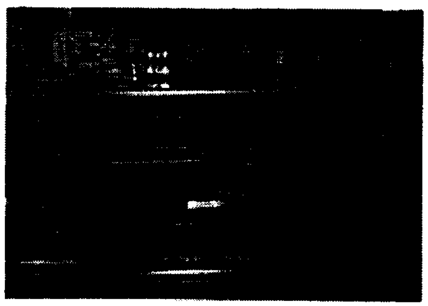
- First flight of a new class of sounding rocket
  - 14" diameter
  - Payload weight including SAMS-FF and Microscale heaters was approx 469 lbs
  - μg time (180-220 seconds)
  - Flown at WFF (water recovery)
- SAMS-FF mission goals
  - Characterize acceleration environment of vehicle during μg period
  - Support Microscale heaters experiment
  - Implement downlink for real-time data display
  - Payload available to support reflights with minor expense



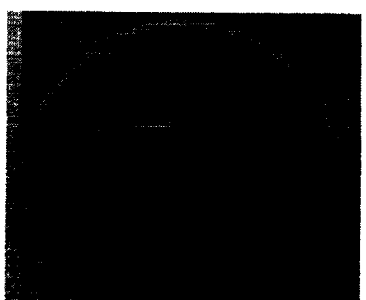
SAMS-FF System Flown on Terrier-Orion Sounding Rocket Flight 41.020 on December 17, 1999.

2.2 Second Drop Tower Characterization

Drop Tower Release Mechanism

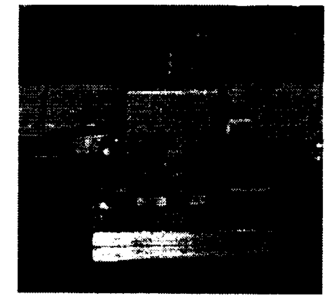


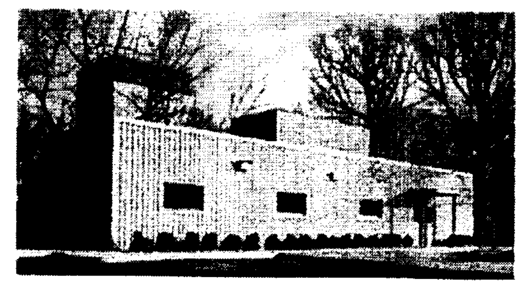
Closeup of Hardware

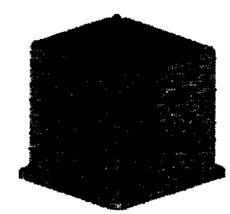


View Down the Drop Tower

- Performed an initial characterization of the acceleration environment of the NASA GRC 2.2 Second Drop Tower
- System consisted of a CDU (RTD) and TSH
- Support week of drops
  - Check acceleration levels
  - Confirm system operation
  - See if any accel bias shift
- Permanent system will be configured based on the results of the testing



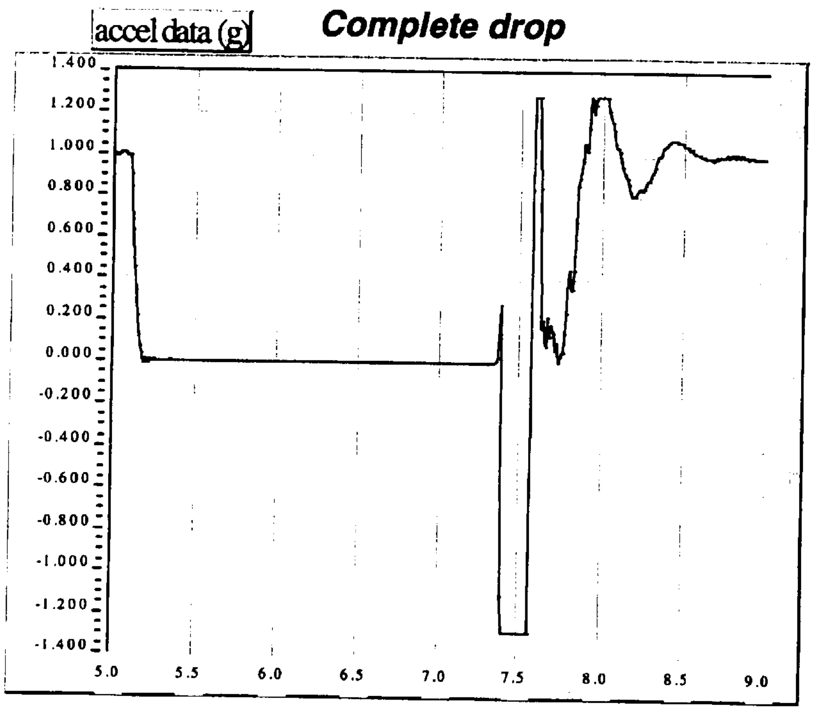




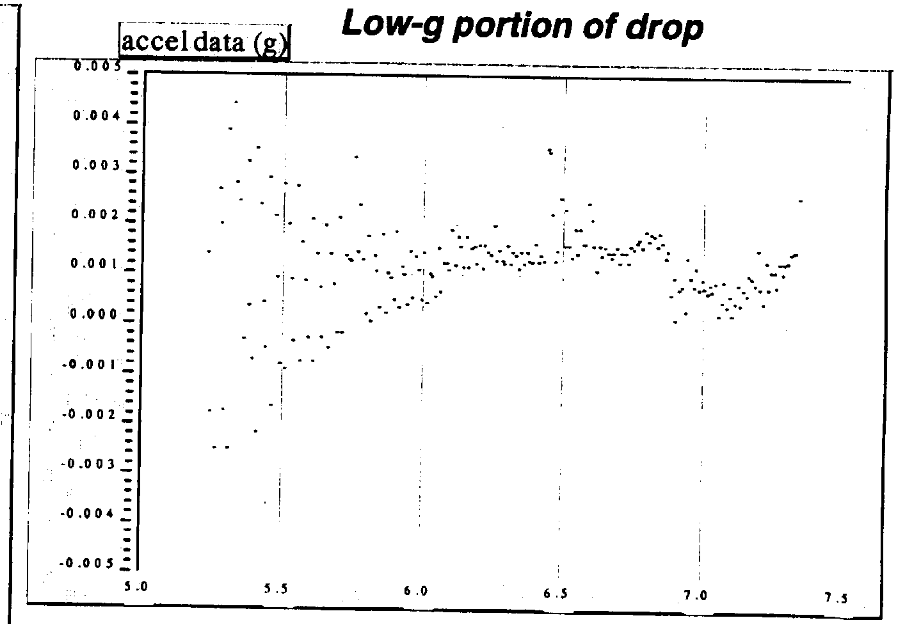
2.2 Second Drop Tower
June 21, 2000

Data from the vertical axis (X) in 2nd drop.

Complete drop

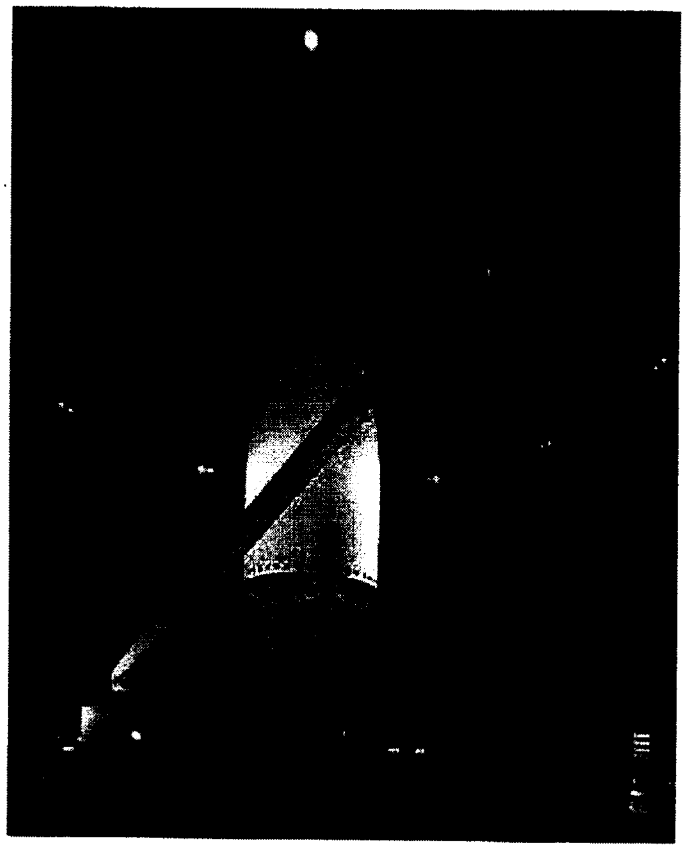


Low-g portion of drop



No appreciable bias or scale factor shift measured on the accelerometers due to the shock of the landing.

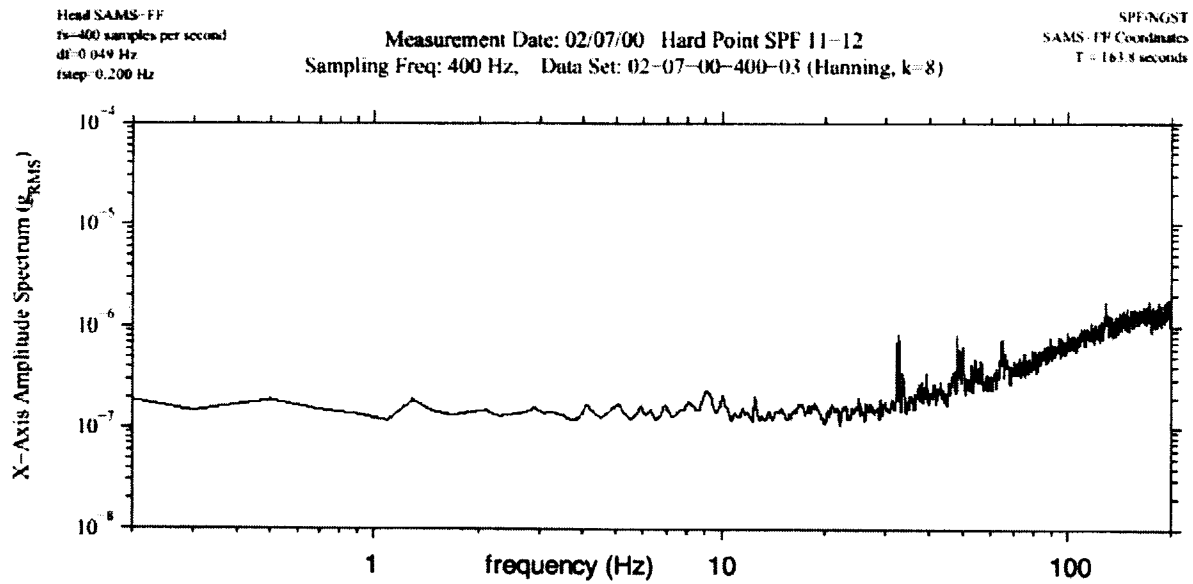
Ground Testing
Plum Brook Station

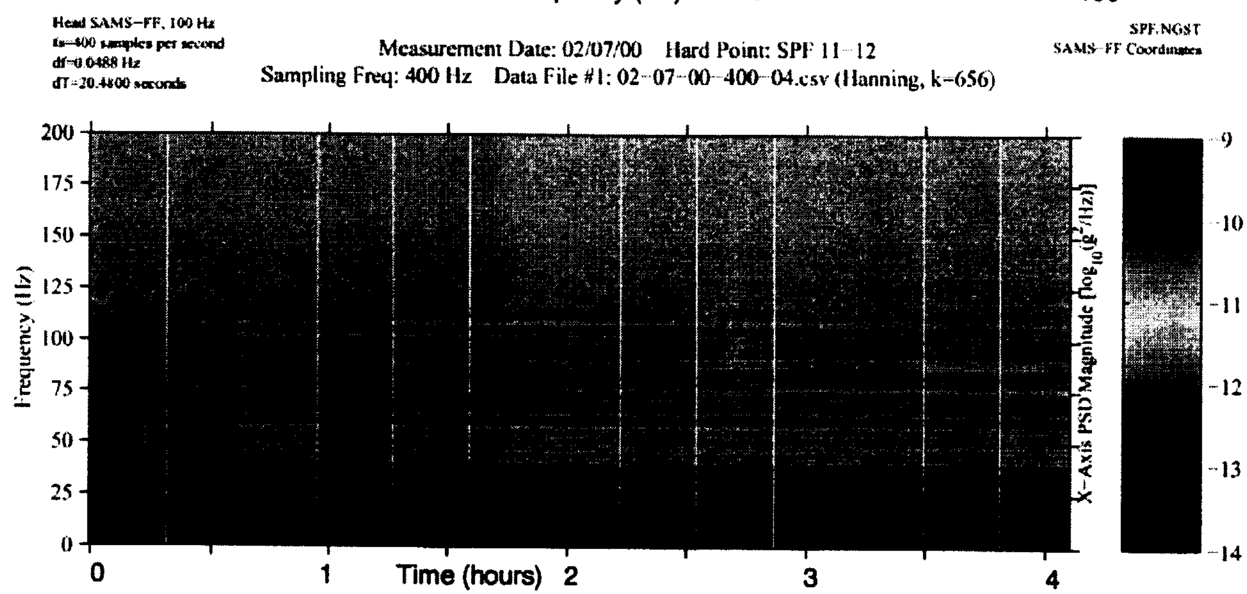


- Requested to characterize accelerations at the Space Power Facility (SPF) at Plum Brook Station

- Requested to characterize accelerations at the Space Power Facility (SPF) at Plum Brook Station
- TSH was used in a standalone mode connected to a SPF computer with SAMS-FF data acquisition software
- Quietest ground environment measured to date (< 0.2μg for 2Hz BW)

Ground Testing – SPF data





Conclusion

- SAMS-FF system is available to support payloads on a variety of different platforms
- System is easily configured to support mission requirements
- Complete service package including hardware and data analysis

- For further information, contact:

- Ron Sicker (216.433.6498)
  ronald.sicker@grc.nasa.gov
- Tom Kacpura (216.977.0420)
  thomas.kacpura@grc.nasa.gov

SAMS-FF Team

- Ron Sicker – NASA Project Manager
- Tom Kacpura – ZIN Tech Project Lead
- Dan Bloom – Technician / Engineer
- Gregory Fedor – Computer Engineer
- Kate McGinnis – Integration Engineer
- Dale Mortensen – Electrical Engineer
- Bruce Smith – Senior Designer
- Dave Vachon - Mechanical Design
- Bruce Johnson – Technical Advisor
- Dave Miller – Advisor Emeritus

2001019715

55/19

513562

42P

Paper Number: 4

Microgravity measurement systems in JEM

Toshitami Ikeda and Keiji Murakami
NASDA, Space Utilization Research Center
Tsukuba-city, Ibaraki, Japan

National Space Development Agency of Japan (NASDA) has been developing a microgravity measurement apparatus (MMA) to be installed in the Japanese Experiment Module (JEM). We can measure microgravity accelerations for each rack position by using MMA. We have the following five experiment equipment on which we need to measure accelerations in the JEM-PM (Pressurized Module) for the first generation.

a) Gradient Heating Furnace

b) Cell Biology Experiment Facility

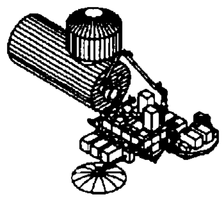
c) Advanced Furnace for Microgravity Experiment with X-ray Radiography

d) Fluid Physics Experiment Facility

e) Solution/Protein Crystal Growth Facility

The MMA will be launched on flight 1J/A in 2003.

JEM vehicle side has a microgravity measurement equipment (MME) for JEM-EF (Exposed Facility). MME consists of three tri-axial acceleration sensors (MME-S) and a data handling unit (MME-D). Measurement data are used for comparison with structural analysis results of JEM-EF and for reflection to the analysis model and method. And the data are also provided for EF payload users. The MME is planned to be launch on flight 2J/A with JEM-EF.

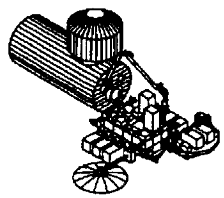


Microgravity Measurement Systems in JEM

19th Microgravity Measurement Group

July 11-13, 2000

Toshitami IKEDA and Keiji MURAKAMI
Space Utilization Research Center,
NASDA

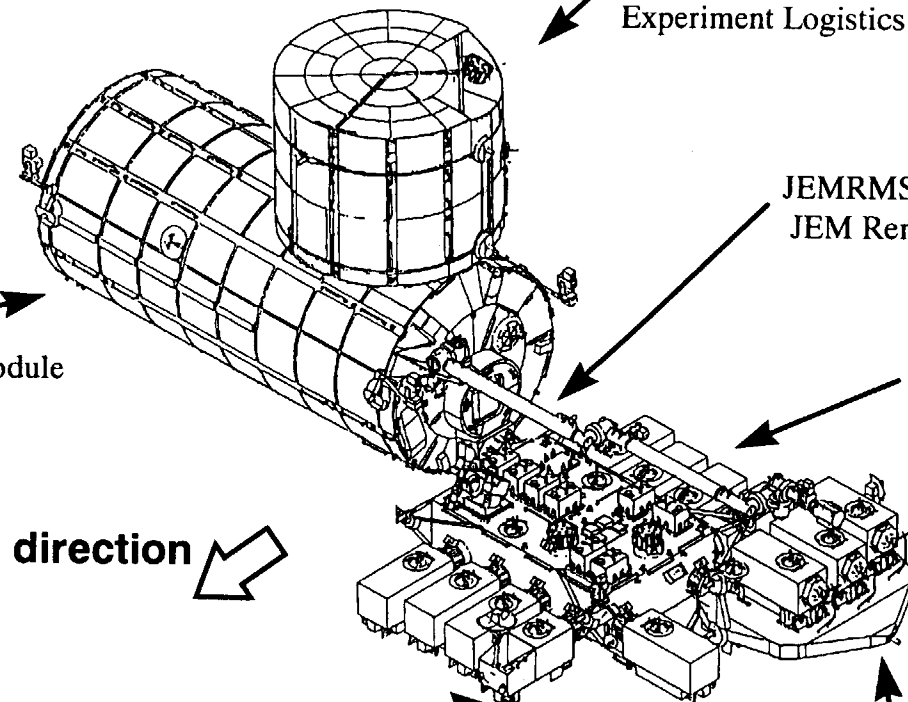


Topics

- **JEM-Microgravity Measurement Apparatus (MMA)**
  - Outline
  - Specifications
  - Development Status
- **Microgravity Measurement Equipment (MME) for JEM-Exposed Facility (EF)**
  - Outline
  - Specifications
  - Operation Concept
- **Development status of Japanese payloads**
  - Information of Japanese Payloads
  - Development Status of Japanese Payloads

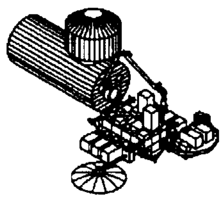
NASDA

Introduction



Japanese Experiment Module(JEM)

NASDA



Outline of JEM-MMA (1/10)

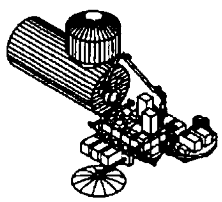
Purpose of the MMA

(1) To provide measurement data for investigators to analyze their experiment results.

(2) To reflect the equipment design of payloads for the next generation.

(3) As a future plan, to validate the JEM-PM structural analysis models, by measuring microgravity accelerations.

NASDA



Outline of JEM-MMA (2/10)

The MMA measures accelerations at the following five equipment in JEM-PM.

a) Gradient Heating Furnace (GHF)

b) Cell Biology Experiment Facility (CBEF)

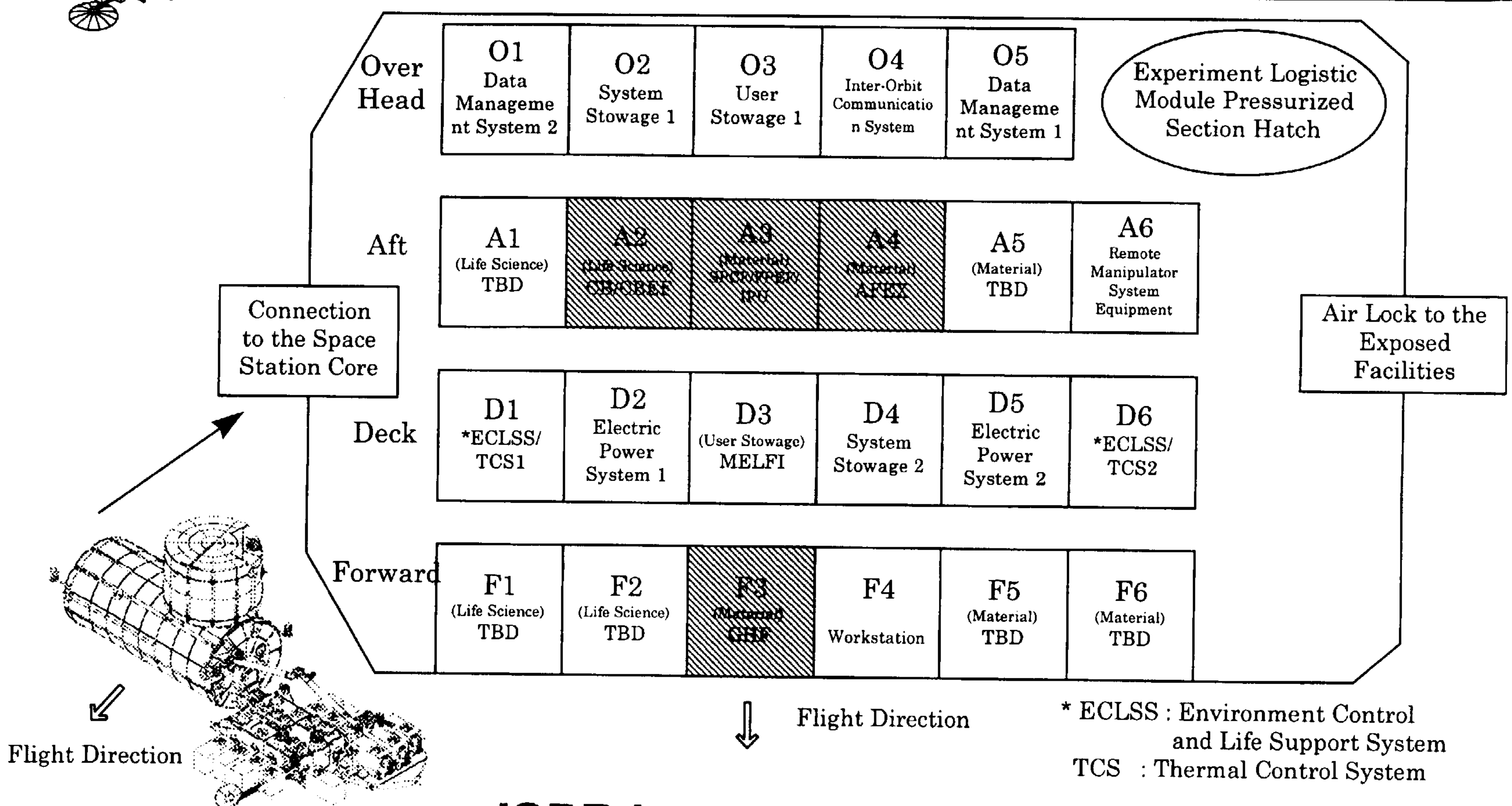
c) Advanced Furnace for Microgravity Experiment with X-ray Radiography (AFEX)

d) Fluid Physics Experiment Facility (FPEF)

e) Solution/Protein Crystal Growth Facility (SPCF)

NASDA

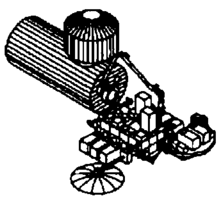
Outline of JEM-MMA (3/10)



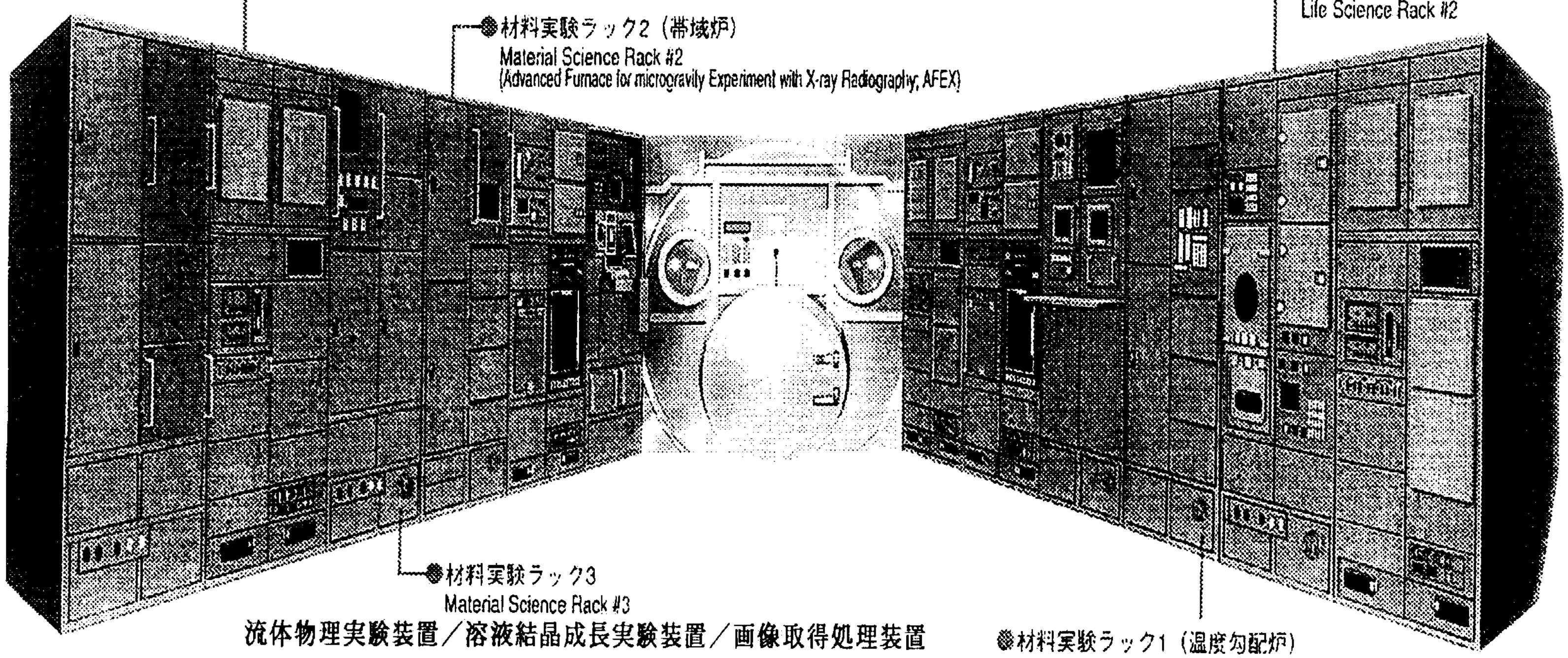
* ECLSS : Environment Control and Life Support System
TCS : Thermal Control System

ISPR layout in JEM-PM

NASDA

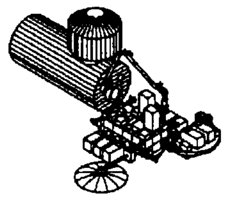


Outline of JEM-MMA (4/10)



inside view of JEM-PM (from Node-2 side)

NASDA

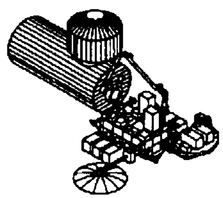


Outline of JEM-MMA (5/10)

Wireless Communication

- The MMA control unit collect data from some acceleration sensors on orbit with wireless communication method. It is compatible with the ISS Wireless Instrumentation System (IWIS).

NASDA



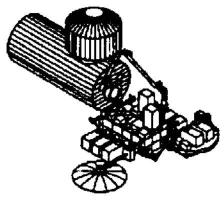
Outline of JEM-MMA (6/10)

MMA composition

- The MMA consist of the following element.

(a) Triaxial Accelerometer Assembly (TAA)...5 ea
(b) Remote Sensor Unit (RSU)......................5 ea
(c) Network Control Unit (NCU)....................1 ea
(d) Microgravity Laptop Terminal (MLT).........1 ea

NASDA



Outline of JEM-MMA (7/10)

(a) Triaxial Accelerometer Assembly (TAA)

- TAA, which have 3 accelerometers, is mounted near the objective payload.

(b) Remote Sensor Unit (RSU)

- RSU, which is utilized to receive the data from TAA, is mounted on each Rack in proportion to the number of TAA.

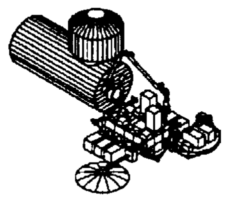
(c) Network Control Unit (NCU)

- NCU, which is a kind of relay device between RSUs and Microgravity Laptop Terminal (MLT), is mounted on a Rack.

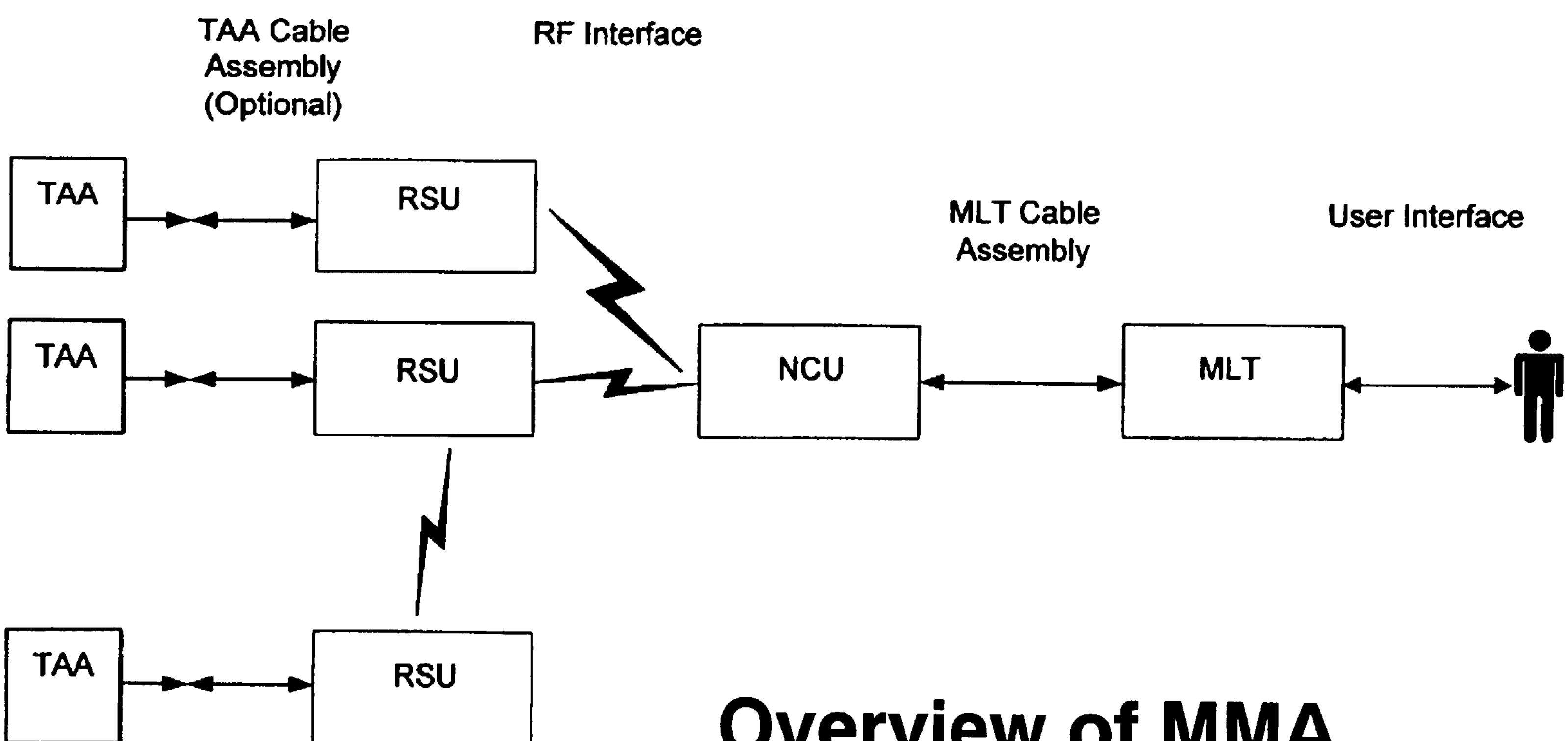
(d) Microgravity Laptop Terminal (MLT)

- MLT, which is used to interface with the Ethernet of JEM, is temporally mounted on a Rack.

NASDA

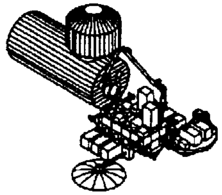


Outline of JEM-MMA (8/10)



Overview of MMA

NASDA



Outline of JEM-MMA (9/10)

MMA Composition

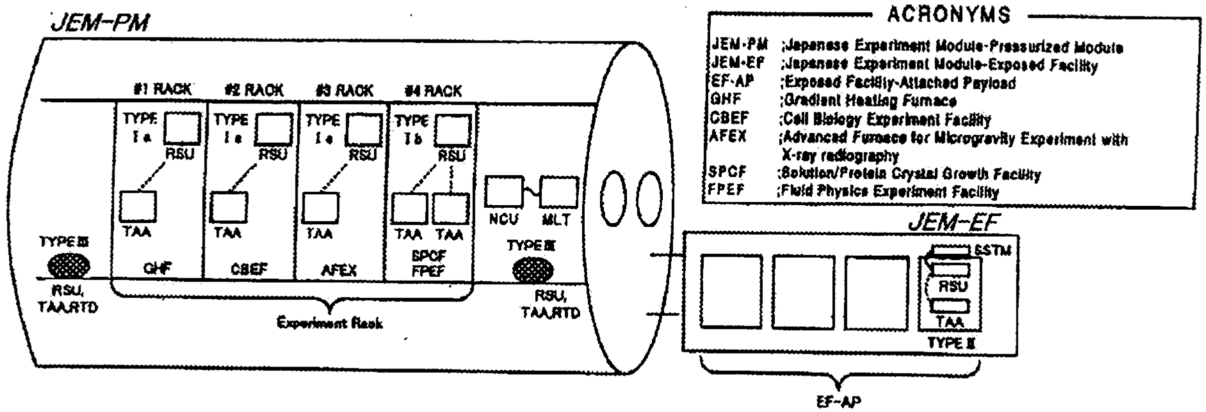
	Current Requirements *1)					Future Plan (Option)			
TAA	O	O	O	O	O		O	O	O
TAA-E						O			
Temperature Sensor	N/A	N/A	N/A	N/A	N/A	N/A	N/A	O	O
RSU	O	O	O	O	O		O	O	O
RSU-E						O			
Power	28VDC	28VDC	28VDC	28VDC	28VDC	28VDC	28VDC	Battery Type	Battery Type
NCU	O (28VDC Power)								
MLT	O (120VDC Power)								
Used for	JEM-PM #1 RACK	JEM-PM #2 RACK	JEM-PM #3 RACK	JEM-PM #4 RACK		JEM-EF Attached Payload	JEM-PM #5 RACK	JEM-PM Environment Monitor	JEM-PM Environment Monitor

*1) : Current requirements involve 5 TAAs, 5 RSUs, 1NCU and 1 MLT.

NASDA

Outline of JEM-MMA (10/10)

• Configuration

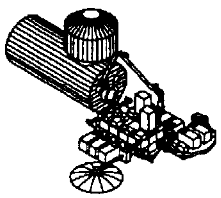


JEM PAYLOAD MMA

TYPE I ······ To Measure Micro-Gravity of each Experiment Facility
······ Power : 120VDC
(TYPE I a) ······ RSU(1ea)+TAA(1ea)······3set
(TYPE I b) ······ RSU(1ea)+TAA(2ea)······1set
TYPE II ······ To Measure Micro-Gravity of EF-Attached Payload
······ Power:28VDC
RSU(1ea)+TAA(1ea)1set······1set
TYPE III ······ To Measure Micro-Gravity & Temperature of JEM environment
Power:Battery
RSU(1ea)+TAA(1ea)+RTD(1ea)······2set(Option)

JEM Micro-Gravity Measurement Apparatus (MMA) Outline

NASDA

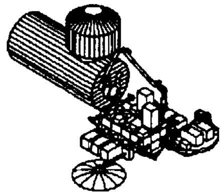


Specifications of JEM-MMA (1/2)

<MMA Specifications (under review)>

• Frequency	0.01～300Hz
• Measurement Range	-250mg～250mg
• Resolution	better than 1 μg
• The absolute accuracy	better than 80 μg

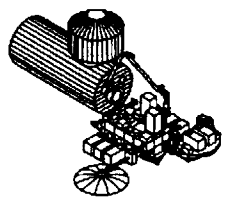
NASDA



Specifications of JEM-MMA (2/2)

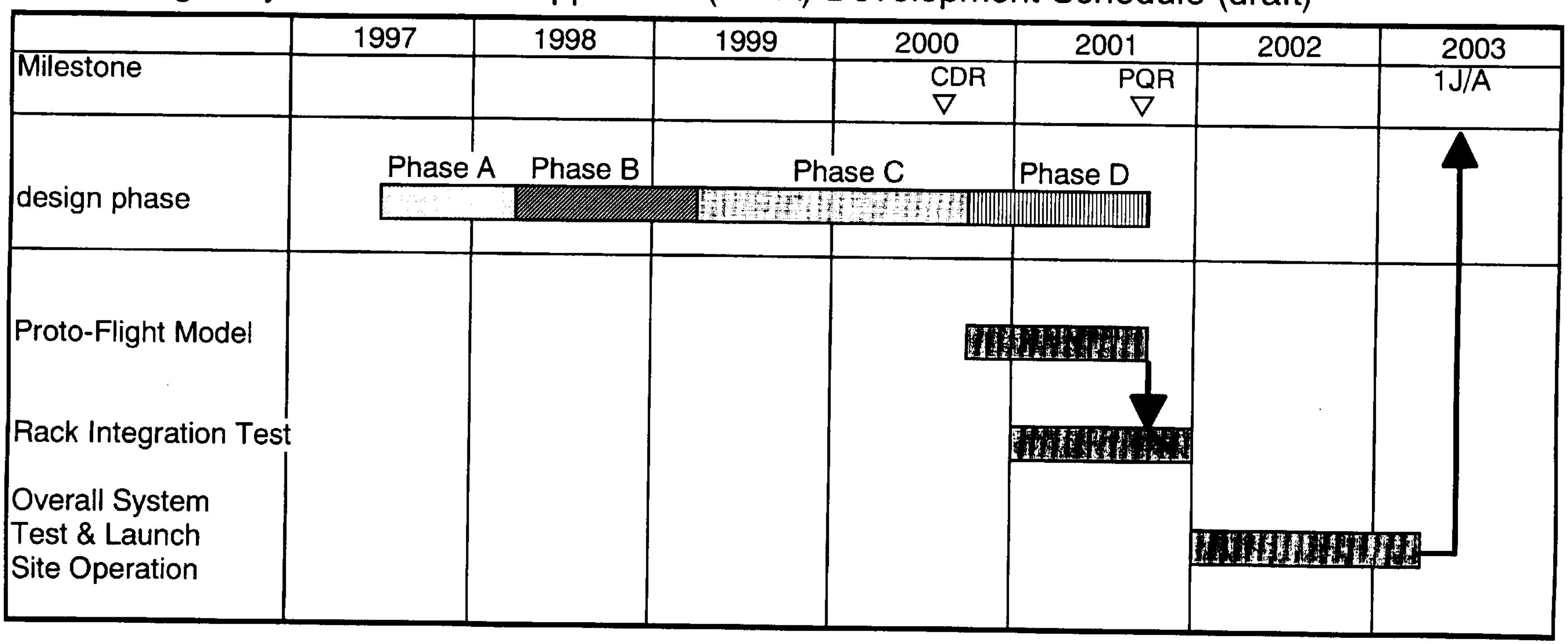
- Approximate size: TAA 3" x 3" x 4"
  - RSU 6" x 4.25" x 4"
  - NCU 6" x 4.25" x 3.5"
- Weight: TAA(with 2m pigtail) 0.9kg
  - RSU 1.6kg
  - NCU 1.4kg
- Power Consumption: TAA less than 1W
  - RSU less than 9W
  - NCU less than 5W

NASDA

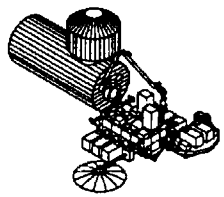


Development Status of JEM-MMA (1/1)

Microgravity Measurement Apparatus (MMA) Development Schedule (draft)



NASDA



Outline of MME for JEM-EF(1/6)

Purpose of the MME

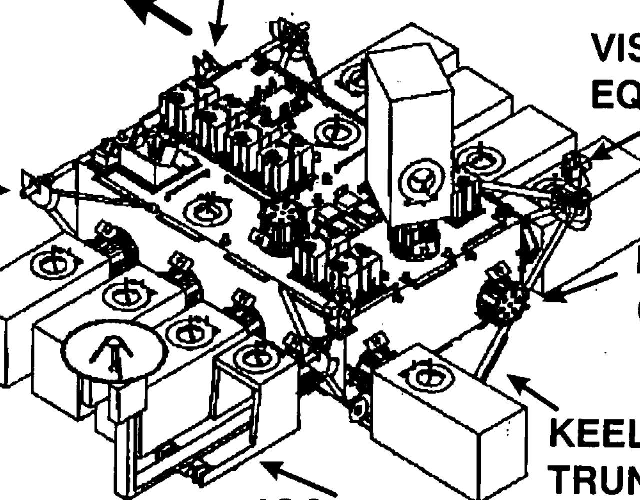
(1) To validate the JEM-EF structural analysis models, by measuring microgravity accelerations.

(2) To reflect the measurement data for structural model and analysis method such as transfer functions, by comparing μg level of each measuring point.

NASDA

Outline of MME for JEM-EF(2/6)

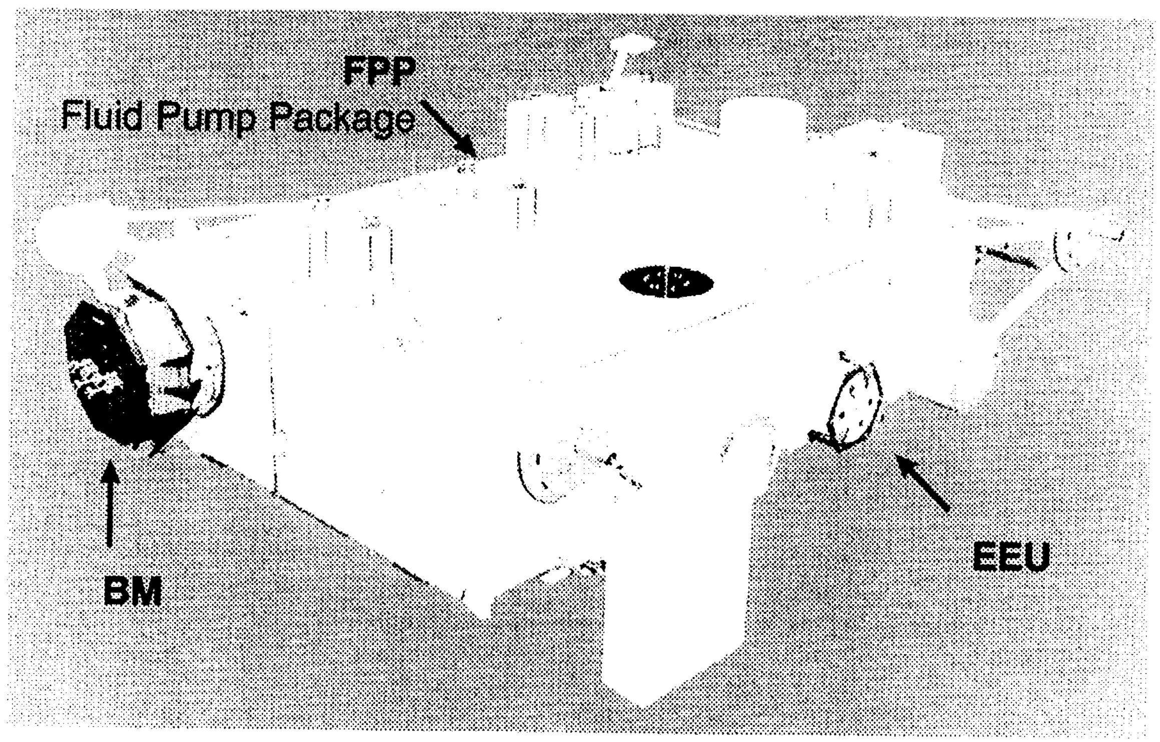
-The JEM exposed facility (EF) is a unique platform for experiments in an environment exposed to space.
-EF payload is attached to JEM-EF with EEU. EEU provides resource utility interfaces of power, data, etc. to the payload.



Configuration of JEM-EF

NASDA

Outline of MME for JEM-EF(3/6)



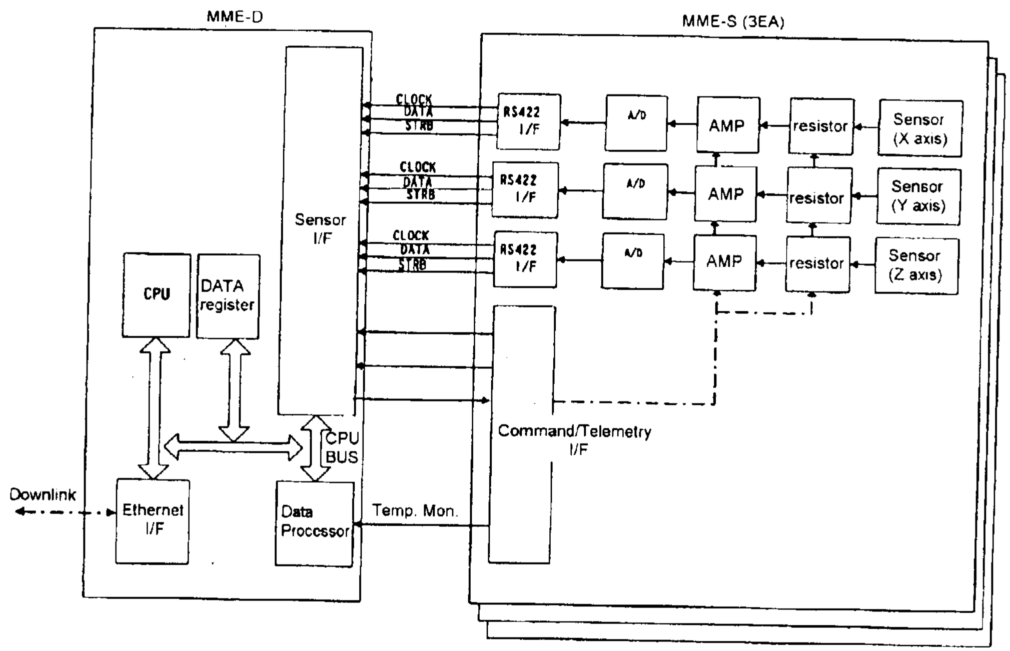
JEM-EF(Engineering Model)

NASDA

Outline of MME for JEM-EF(4/6)

Composition of MME

- Microgravity Measurement Equipment (MME)
  - MME Data Processing Unit (MME-D) : 10kg x 1ea
  - MME Sensor (MME-S) : 3.6kg x 3ea



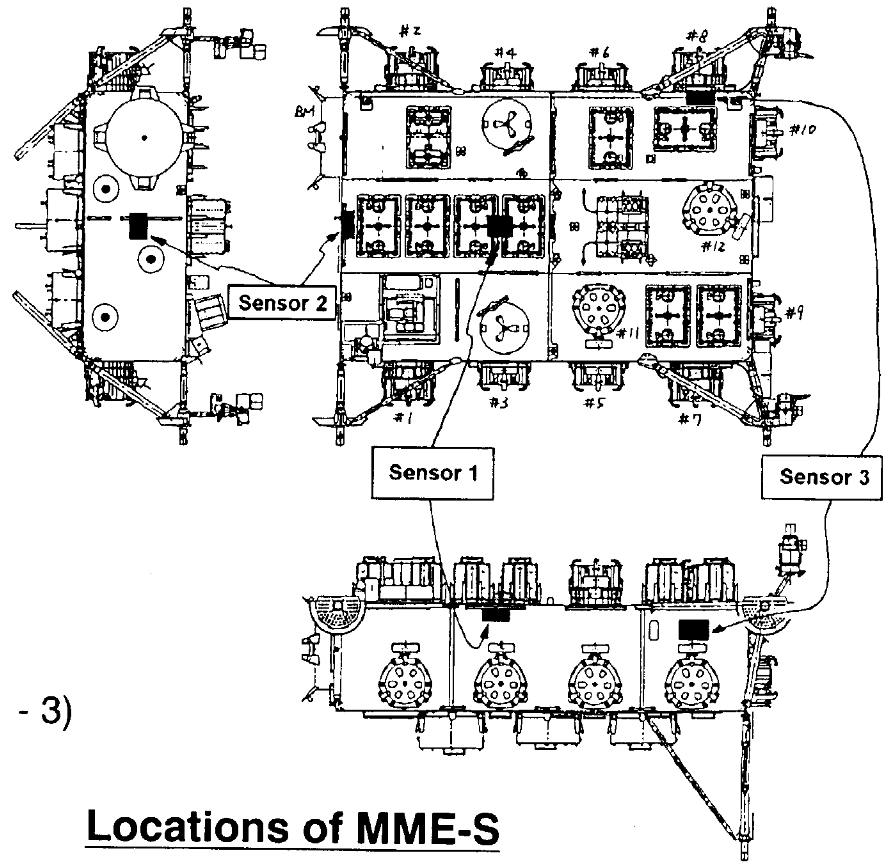
Concept of MME System (Analog signal)

NASDA

Outline of MME for JEM-EF(5/6)

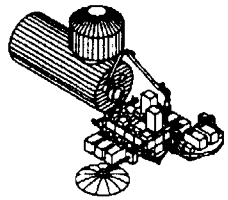
Three MME-Ss on the JEM-EF.
- Nearby FPP
- Both end of JEM-EF

Target
- FPP disturbance (Sensor 1)
- Global mode vibration (sensor 1 - 3)



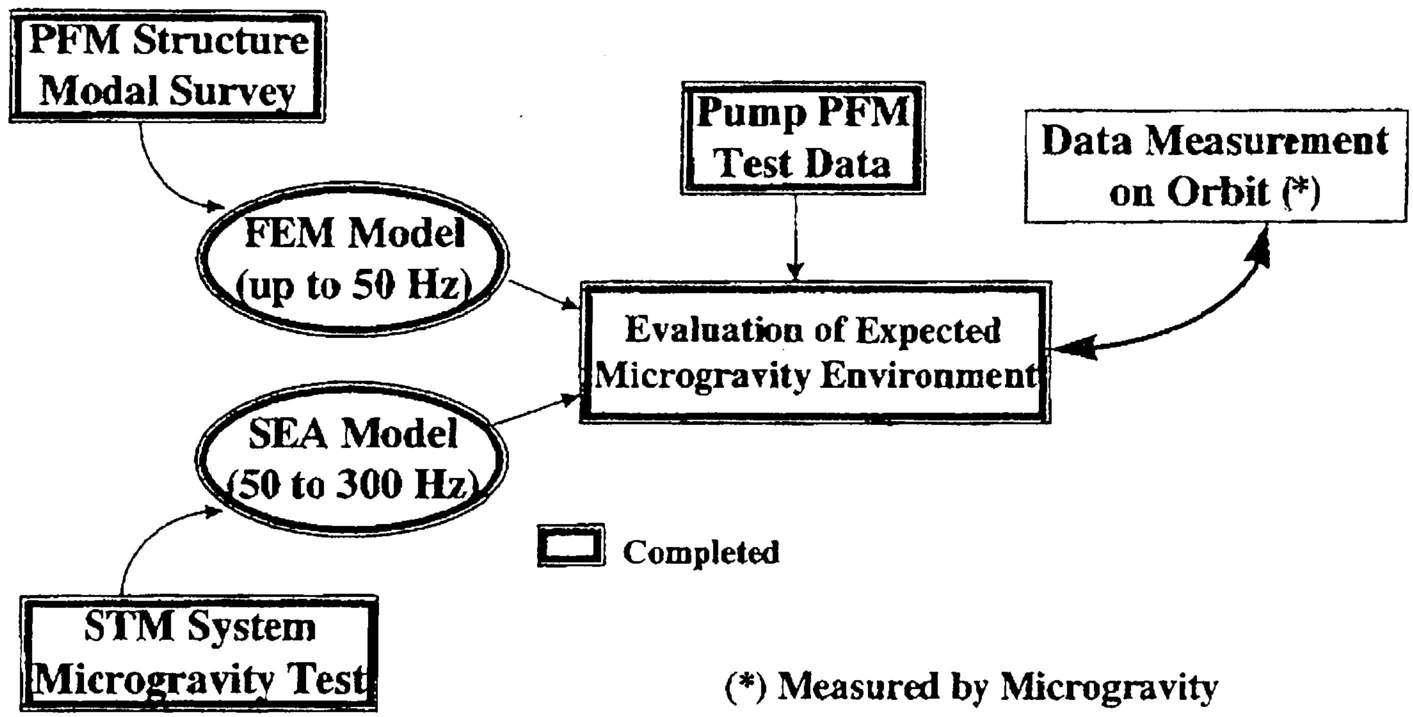
Locations of MME-S

NASDA



Outline of MME for JEM-EF(6/6)

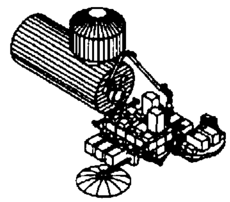
Expected microgravity environment



(*) Measured by Microgravity Measurement Equipment (MME)

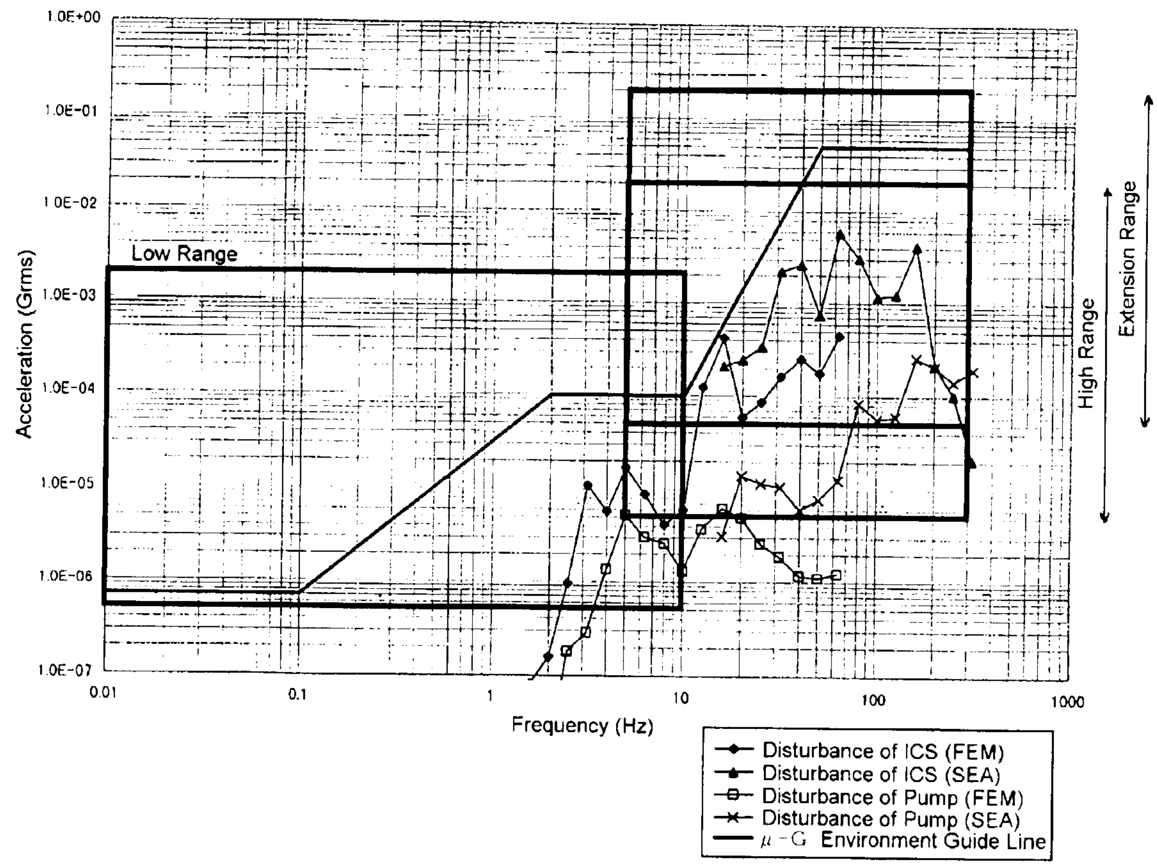
Microgravity Analysis

NASDA



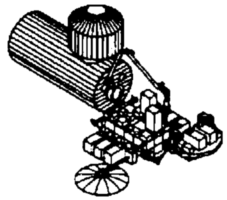
Specifications of MME(1/2)

Measurement Range of MME



Analysis of JEM-EF Microgravity Environment

NASDA



Specifications of MME(2/2)

<MME Specification>

Frequency and Acceleration

-Low Range

0.01 – 10 Hz $1.0 \times 10^{-6} - 2.0 \times 10^{-3}$G

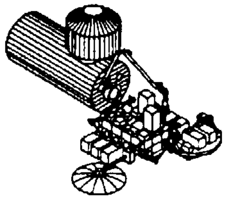
-High Range

5.0 – 300 Hz $5.0 \times 10^{-6} - 2.0 \times 10^{-2}$G

-Extension range

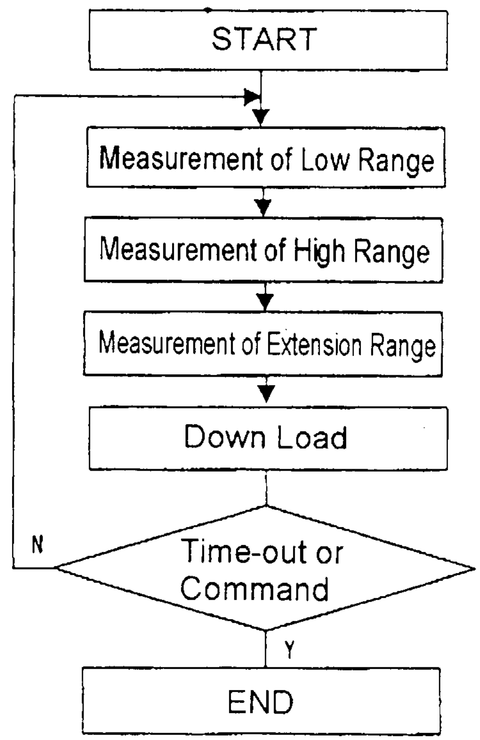
5.0 - 300Hz $5.0 \times 10^{-5} - 2.0 \times 10^{-1}$G

NASDA



Operation Concept of MME(1/2)

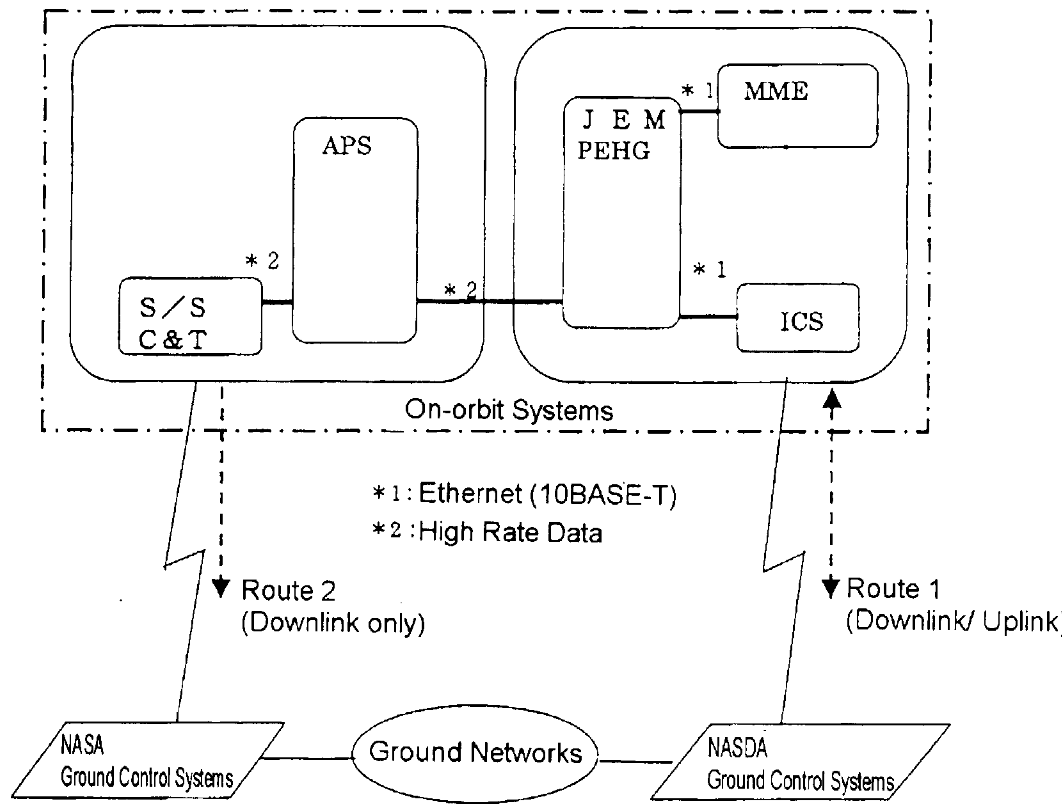
MME Measurement Sequence



Data Processing Sequence of MME-D

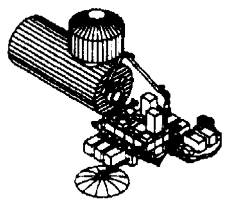
NASDA

Operation Concept of MME(2/2)



Communications between MME and Ground Systems

NASDA



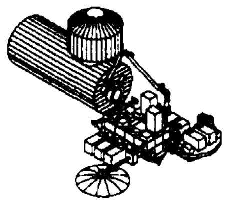
Development Status of Japanese Payloads (1/13)

Japanese Payloads (first generation)

Microgravity Science field	Life Science field	Support Equipment	Attached Payload
Gradient Heating Furnace (GHF)	Cell Biology Experiment Facility (CBEF)	Image Processing Unit (IPU)	Space Environment Data Acquisition equipment-Attached Payload (SEDA/AP)
Advanced Furnace for Microgravity Experiment with X-ray Radiography (AFEX)	Clean Bench (CB)	[Minus Eighty Degrees Laboratory Freezer for ISS (MELFI)]	Monitor of All-sky X-ray Image (MAXI)
Fluid Physics Experiment Facility (FPEF)			Laser Communications Demonstration Equipment (LCDE)
Solution/Protein Crystal Growth Facility (SPCF)			Superconducting Submillimeter-Wave Limb-Emission Sounder (SMILES)

http://jem.tksc.nasda.go.jp/kibo/kibomefc/index_e.html

NASDA



Development Status of Japanese Payloads (2/13)

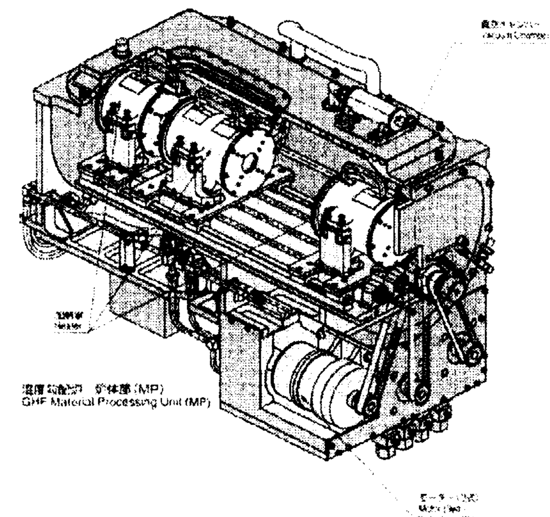
GHF(Gradient Heating Furnace)

General Description

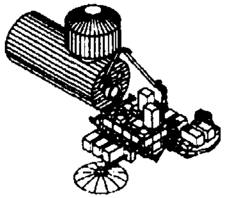
The Gradient Heating Furnace (GHF) is an experiment facility for investigating crystal growth and gaseous phase growth of semiconductors. The GHF is a multiuser furnace consisting of the Material Processing Unit (MP), which directly operates the heating and cooling process of samples; the GHF Control Equipment (GHF-CE), which controls the overall operation of the GHF and communicates with Kibo; the Sample Cartridge Automatic Exchange Mechanism (SCAM), which can automatically exchange 15 samples cartridges (max); and the SCAM Control Equipment (SCAM-CE). The MP has three independent heating zones that can provide various temperature profiles in accordance with the experiment requirements under vacuum conditions. This furnace has the capability of directional solidification of samples. In order to conserve crew resources on orbit, the sample cartridges are automatically exchanged by SCAM. Ten channel thermocouples allow measurement of the sample temperature distribution.

Specifications

Heating Range	500 to 1600°C
Temperature Stability	±0.2°C at 1600°C, 1 hour
Temperature Gradient	Max. 150°C/cm at 1450°C, Sample dependent
Translation Rate	0.1 to 200mm/hr.
Temperature Monitoring	5 points (Max. 10 points)

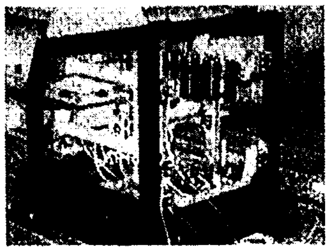


NASDA

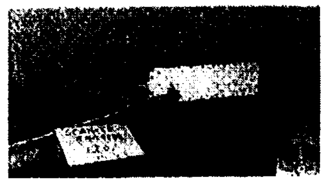


Development Status of Japanese Payloads (3/13)

#1 KOBAIRO Rack (GHF)

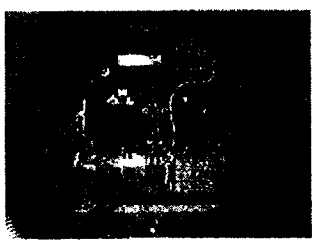


Sample Cartridge Automatic Exchange mechanism(SCAM)



Control Equipment

Rack Structure



GHF-Material Processing Unit

GHF Assembly

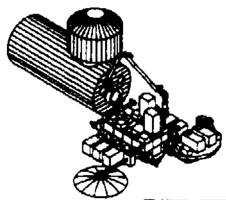
KOBAIRO Rack

KOBAIRO Rack

1999									2000													2001							
4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8

Component Manufacturing	GHF System Test	Rack Integration Test

NASDA



Development Status of Japanese Payloads (4/13)

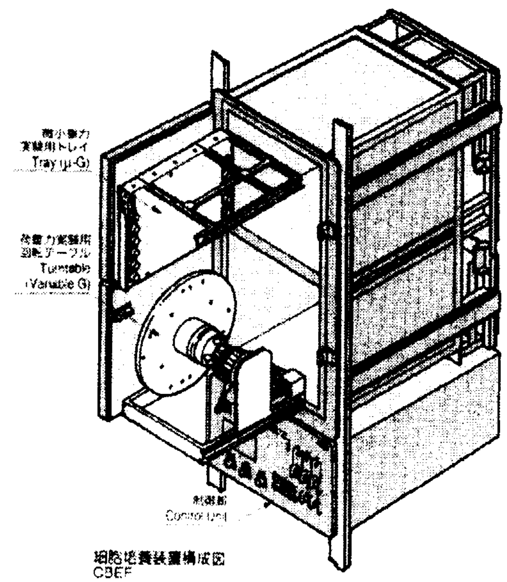
CBEF(Cell Biology Experiment Facility)

General Description

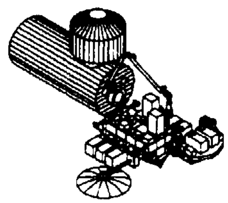
The Cell Biology Experiment Facility (CBEF) provides a controlled environment (temperature, humidity and CO2 concentration) for studying fundamental phenomena of life in the space environment, using cells, tissues, small animals, plants, or microorganisms. The CBEF will be equipped with a turntable that provides variable gravity for reference experiments. Each experiment will be put in small containers called "canisters" that are placed on the incubator tray or rotating table in the CBEF. (Three canister sizes, Large, Medium and Small are available.) Canisters will be supplied with power, command, sensors, and video interfaces through the utility connectors, thus efficiently supporting experiments. Experiments in the canisters can be manually handled inside Kibo's Clean Bench. NASDA also provides a Biological Experiment Unit specially designed for Medium canister.

Specifications

Style	CO2 incubator	
Dimensions	1/2DR W482 x H1243 x D660mm	
Volume	μ-G 60 litters	
	Variable-G 70 litters	
Environment control	Temperature control	15℃ to 40℃
	Humidity control	Max. 80%±10%RH
	CO2 control	0 to 10% Volume
	Variable gravity	Turntable{20~140rpm (equivalent to 0.05 to 2.0g inside the canister)}
User Interface	Power DC +5V, +12V, ±15V	
	Video output	
	1bit command	
	Sensor output 0 to 5 Volts	
	RS485 connector (through front panel)	



NASDA



Development Status of Japanese Payloads (5/13)

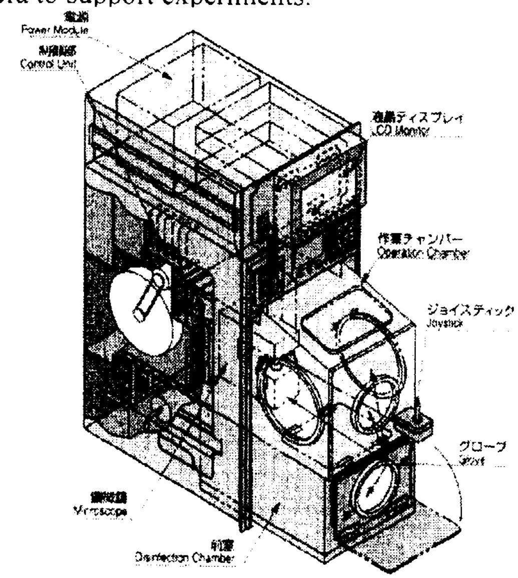
CB(Clean Bench)

General Description

The Clean Bench (CB) provides a closed work space for aseptic operation in order to perform life science and biotechnology experiments in Kibo. The CB has a disinfection chamber to prevent biocontamination. The disinfection chamber provides a compartment for sterilization, and all experiment samples and equipment (such as cell culture chamber) must go through this chamber before and after experiments inside the operation chamber. An HEPA filter provides class-100- equivalent clean air inside the operation chamber, as well as a sterilized environment by using alcohol and an ultraviolet lamp. The operation chamber front panel will be made of transparent material to facilitate aseptic operations with visual observation. The operation chamber is equipped with a phase contrast/fluorescence microscence microscope and CCD monitoring camera to support experiments.

Specifications

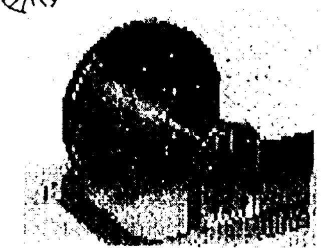
Style	Drawer type glove box	
Dimensions	1/2DR W482 x H1243 x D660mm	
Volume	Operation chamber 52 litters	
	Disinfection 14 litters	
Support equipment inside operation chamber	Phase contrast/fluorescent Microscope object lens x4, x10, x20, x40 (Magnification)	
	Monitoring camera	
Environment control	Cleanliness	Particle elimination by HEPA filter
	Stenrilization	Alcohol, UV lamp
	Temperature control	20°C to 38°C
Environment Monitor	Temperature, Organic gas, Particle	
User Interface	Power DC +5V, +12V, ±15V	
	Video output connector	
	User connectors	



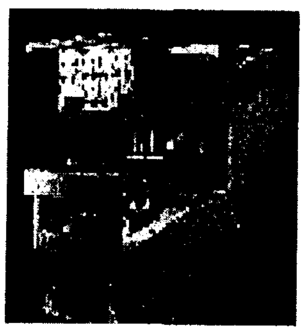
NASDA

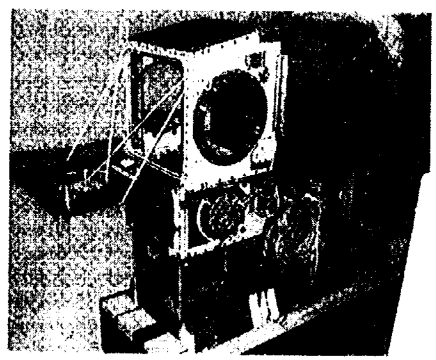
Development Status of Japanese Payloads (6/13)

#2 SAIBO Rack (CBEF, CB)


1g Rotor


CBEF Incubator


Phase Contrast/
Fluorescence Microscope


CB Operation Chamber


Rack Structure

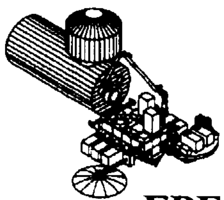

SAIBO Rack

SAIBO Rack

1999									2000												2001							
4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8

Component Manufacturing	CBEF, CB System Test	Rack Integration Test

NASDA



Development Status of Japanese Payloads (7/13)

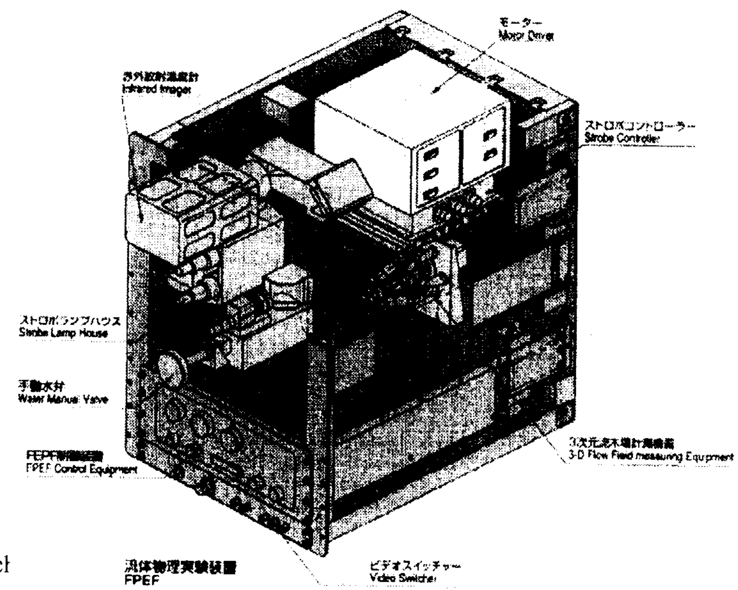
FPEF(Fluid Physics Experiment Facility)

General Description

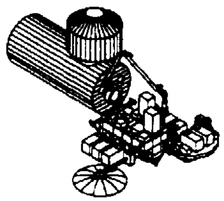
The Fluid Physics Experiment Facility (FPEF) is used to conduct fluid physics experiments in a moderate temperature environment. In the microgravity environment, marangoni convection, which is driven by the difference of surface tension, significantly influences convection. The purpose of this facility is to investigate the effects of the marangoni convection on space experiments (Semiconductor crystal growth in the Floating Zone method). Observing the marangoni convection is considered to be a prerequisite for future techniques such as controlling marangoni convection and applying marangoni convection to remove air bubbles in liquids. The FPEF's observation capabilities include two/three dimensional flow field observations, surface temperature measurement, ultrasonic velocity profile measurement and surface-flow rate observation. Currently, Marangoni convection research with a liquid bridge is planned, and suitable experiment units are being developed for that purpose.

Specifications

Liquid Bridge	Diameter	ϕ30, 50mm
	Length	0 ~ 80mm
	Amount of liquid is controllable.	
Temperature Control	Heating Disk:	Up to 100°C
	Cooling Disk:	Down to 5°C
Atmosphere Control	Pressure	Up to 98KPa Ar
Liquid Bridge	Surface (infrared imager)	0 to 10°C
Temperature	Inside (thermocouples)	Accuracy ±1°C
3D Flow Field	CCD camera:	resolution 460 (H) x 350 (V)
	Strobe light:	flash rate 60Hz
Liquid Bridge Over View	3 CCD cameras:	resolution 570 (H) x 350 (V)
Surface Flow	Photochromic dye actuation with GN2 laser:	Focus depth: ±0.5mm Resolution: 60m (Max.)
Internal Flow Field	UVP sensors	Measurement points:150 (Max.) Space resolution: 0.47mm/5Hz(Min.) Frequency: 5Hz (Min.)
Other utilities supplied for the Mission Section	Envelop	W229.9 x H363 x D510mm
	Power	+24V (1ch), 12V (1ch), ±15V(2ch
	Video output	NTSC (2ch)
	Gas supply	Ar



NASDA



Development Status of Japanese Payloads (8/13)

SPCF(Solution/Protein Crystal Growth Facility)

General Description

The Solution/Protein Crystal Growth Facility (SPCF) can provide opportunities for fundamental studies of crystal growth of various solutions and proteins in space. SPCF consists of two major units, the Solution Crystallization Observation Facility (SCOF) and the Protein Crystallization Research Facility (PCRF).

SCOF(Solution Crystallization Observation Facility)

SCOF has a cell cartridge for growing the crystal in solution. It grows crystals by controlling the temperature and pressure and is used to conduct real-time observation. SCOF has observation facilities of two wavelength Mach-Zehnder interferometer microscope, Michelson interferometer microscope and light scattering measurement to allow observation of the crystallization and the crystal surface and measurement of the temperature of the liquid phase, the concentration distribution and of the particle size.

Specifications of SCOF

- Observation of Crystal Surface
  - Amplitude Modulation Microscope
    - Light Source: LED (λ =660nm)
    - Direction: Penetration/Reflection
    - Magnification: x2, x4
    - Resolution: $\leqq 1\,\mu$m
  - Real-time Phase Shift 2-Wavelength Microscope Interferometer
    - Light Source: Laser (λ =532,780nm)
    - Magnification: x3 (Fixed)
    - Phase Dif. Resolution: $\leqq 0.02\lambda$
- Observation of Concentration and Temperature Distribution
  - 2-Wave Mach-Zehender Microscope Interferometer
    - Light Source: Laser (λ =532,780nm)
    - Magnification: x2, x4
    - Phase Dif. Resolution: $\leqq 0.2\lambda$
- Measurement of Particle Size Distribution
  - Dynamic Light Scattering Measurement
    - Light Source: LD (λ =532nm)
    - Smallest Particle: Order of 10nm
    - Analyzer: Photon Correlation Method
    - Self-Correlation Channels: 288 (Max.)
- Crystal Growth Cell
  - Temperature Control Function -1 to 220°C

NASDA

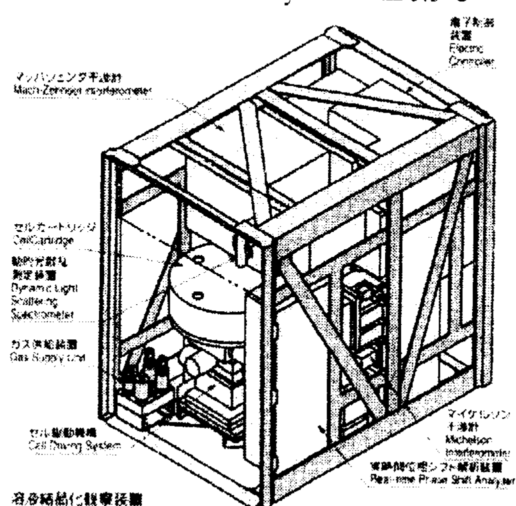
Development Status of Japanese Payloads (9/13)

PCRF(Protein Crystallization Research Facility)

PCRF grows large, high-quality protein crystals for ground analysis. The two units described above can be operated independently as two separate facilities.

specifications of PCRF

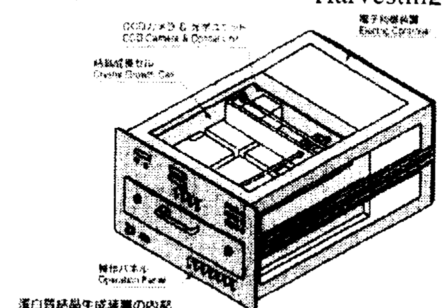
Crystal Observation		
Imaging device		1/2CCD camera(TBD)
Number of pixels		379,000
Resolution		40 μ m
Light		LED
Thermal control	Control range	0 to 35℃
	Accuracy	±0.5℃



BCOF

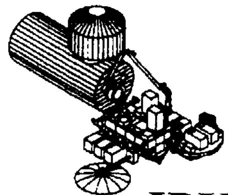
Common cell cartridge

Cell cartridge envelope (mm)	100 x 69/cartridge
Number of cartridges in PCRF	6
Maximum number of cells in a cartridge	
10 for vapor diffusion and membrane partitioned two-liquid diffusion	
16 for batch-leave-at-rest and liquid-liquid interface two-liquid diffusion	
Number of thermal sensors	2/cartridge
Crystallization methods	
1)Batch-leave-at-rest method	
2)Membrane partitioned two-liquid diffusion method	
3)Liquid-liquid interface two-liquid diffusion method	
4)Vapor diffusion method	
Volume of sample (μ litters)	10-500
Stopping method	Harvesting reagent purge method



PCRF

NASDA



Development Status of Japanese Payloads (10/13)

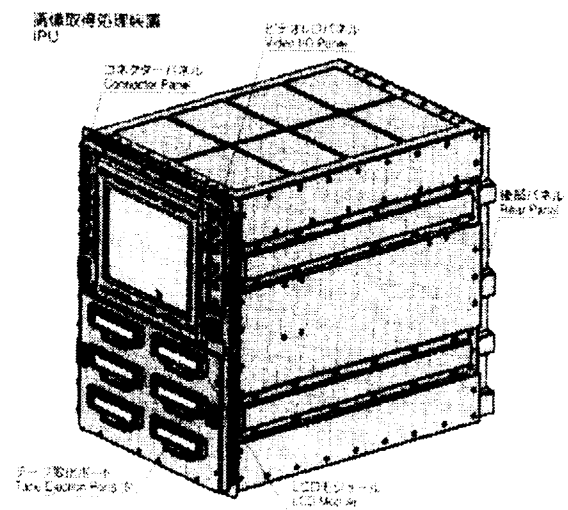
IPU(Image Processing Unit)

General Description

The Image Processing Unit (IPU) receives image data from various experiment equipment in Kibo, encodes and compress those data, then transfers the encoded data to Kibo system lines. The IPU also records experimental image data on tape in VTR systems when real-time data downlink is not possible. The main functions of the IPU are to have various interfaces with Kibo systems and experiment equipment, to receive and compress five channels of independent motion video signals simultaneously, and to record video signals on the tape with five digital VTR's continuously (up to 120 min. each).

Specifications

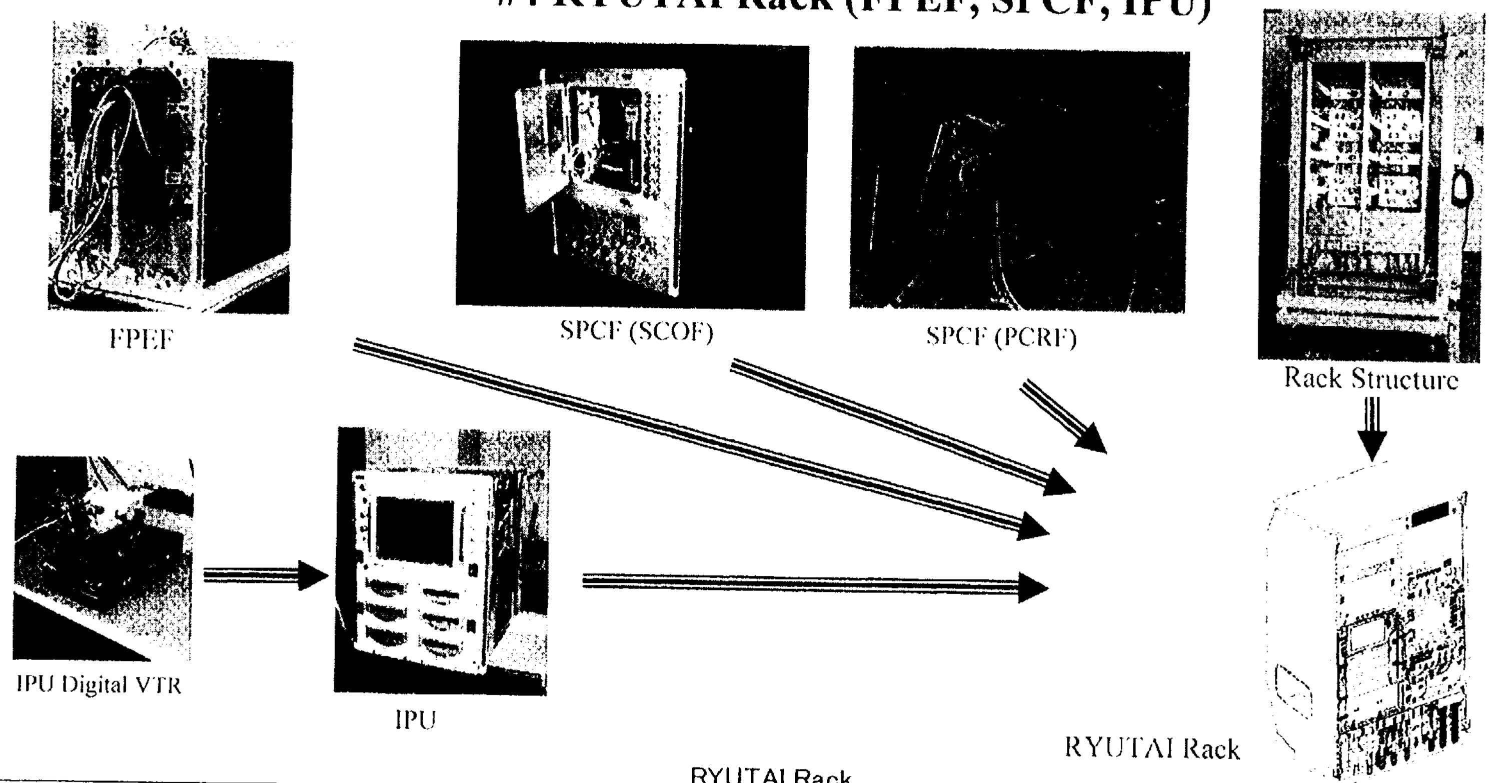
Dimensions	1/4 DR	W482 x H621 x D660mm
Interface	1553B, RS422, Video signal, Ethernet, HRDL	
In/out data	In	NTSC video, Telemetry, Operation Commands, Digital Still Image
	Out	H&S Data, Control Commands, Compressed data (MPEG2)
Image Processing	MPEG2	
		5ch compression, 1ch Decompression,
Data Storage	Digital VTR (x6), Removable HD	
Crew I/F	Operation Panel, 12.1 inch LCD	



NASDA

Development Status of Japanese Payloads (11/13)

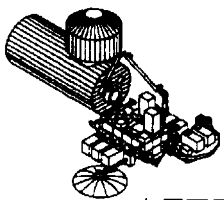
#4 RYUTAI Rack (FPEF, SPCF, IPU)



RYUTAI Rack

1999									2000												2001							
4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8
Component Manufacturing																	FPEF,SPCF,IPU System Test								Rack Integration Test			

NASDA



Development Status of Japanese Payloads (12/13)

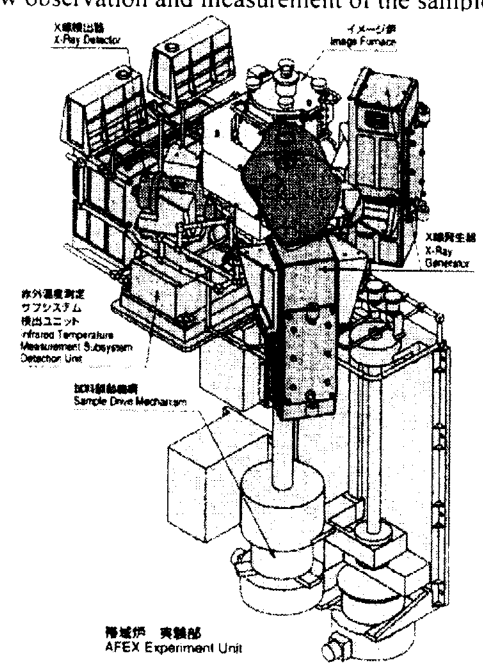
AFEX(Advanced Furnace for microgravity Experiments with X-ray radiography)

General Description

The Advanced Furnace for microgravity Experiments with X-ray radiography (AFEX) can perform single-crystal growth experiments by the Floating Zone method. AFEX is a multiuser furnace that has the capability of real-time observation of semiconductor crystallization and marangoni convection by using X-ray radiography. The AFEX has a gold-plated ellipsoidal mirror. The sample placed in one focus of the mirror is heated and melted by the radiation of a 1500W halogen lamp, placed in the other focus. With ceramic heaters attached around the samples, AFEX can perform isothermal heating experiments or thermal gradient control experiments. X-ray radiographies (two axes), a sample monitor camera, an infrared thermometer, and five channel thermocouples allow observation and measurement of the samples.

Specifications

Lamp Heating	
Max. lamp power	1500W
Heating range	Max.1600°C, Sample dependent
Temperature stability	±3°C at 1450°C
Ceramic Heating	
Max. Heating power	1500W
Heating range	200 to 1450°C, Sample dependent
Temperature stability	±3°C at 1450°C
Common	
Sample translation stroke	±25mm
Sample translation speed	0.1 to 1000mm/hr
Sample rotation	0.01 to 10rpm
Monitor	X-ray radiography (two axes)
	Infrared thermometer
	Sample monitor camera
	5 thermocouples
Gas supply	Ar, N2 and others



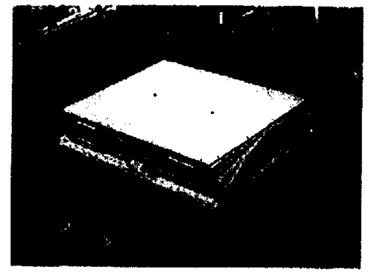
AFEX Experiment Unit

NASDA

Development Status of Japanese Payloads (13/13)

#3 TAIKIRO Rack (AFEX)

X-ray Generator



Controller

Rack Structure

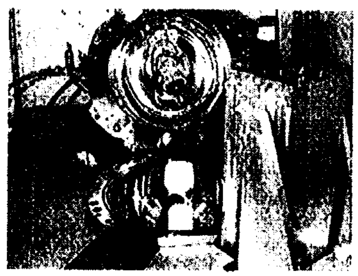
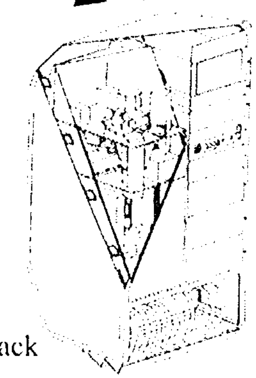


Image Furnace

AFEX Assembly

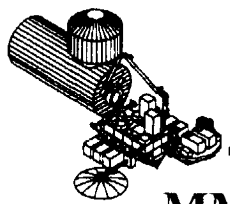


TAIKIRO Rack

TAIKIRO Rack

1999									2000												2001							
4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8
Component Manufacturing													AFEX System Test											Refurbish				

NASDA



Summary

MMA

- Microgravity on the ISPRs and the Attached Payloads on the JEM-EF are measured by JEM-MMA to provide investigators.

MME

- Microgravity on the EF itself is measured by MME to evaluate the analytical scheme.
- Obtained data is expected to be used for ISS total structural dynamics analysis.

Japanese Payloads

- NASDA is developing many kinds of multi-user experiment facilities for the Pressurized Module of JEM. For Exposed Facility. we are developing 4 attached payloads.

Suggestion

- Investigators would like to know how is the microgravity environment on the ISS. For the international AO, quasi-steady and vibratory analysis result for each ISPR location by the latest DAC should be available for them on the external Web Page.

NASDA

56/19 2000101971 512563 10p

Paper Number: 5

Microgravity outreach and education

Melissa J. B. Rogers and Carla B. Rosenberg
National Center for Microgravity Research in Fluids and Combustion
Cleveland, Ohio

The NASA Microgravity Research Program has been actively developing classroom activities and educator's guides since the flight of the First United States Microgravity Laboratory. In addition, various brochures, posters, and exhibit materials have been produced for outreach efforts to the general public and to researchers outside of the program. These efforts are led by the Microgravity Research Outreach/Education team at Marshall Space Flight Center, with classroom material support from the K-12 Educational Program of The National Center for Microgravity Research on Fluids and Combustion (NCMR), general outreach material development by the Microgravity Outreach office at Hampton University, and electronic/media access coordinated by Marshall.

The broad concept of the NCMR program is to develop a unique set of microgravity-related educational products that enable effective outreach to the pre-college community by supplementing existing mathematics, science, and technology curricula. The current thrusts of the program include summer teacher and high school internships during which participants help develop educational materials and perform research with NCMR and NASA scientists; a teacher sabbatical program which allows a teacher to concentrate on a major educational product during a full school year; frequent educator workshops held at NASA and at regional and national teachers conferences; a nascent student drop tower experiment competition; presentations and demonstrations at events that also reach the general public; and the development of elementary science and middle school mathematics classroom products.

An overview of existing classroom products will be provided, along with a list of pertinent World Wide Web URLs. Demonstrations of some hands on activities will show the audience how simple it can be to bring microgravity into the classroom.

Microgravity Outreach and Education

Melissa J. B. Rogers
NCMR Educational Programs Manager

19th Microgravity Measurements Group Meeting
Cleveland, Ohio
11 July 2000

Microgravity Educational Outreach

A means to inspire

pre-college educators,

students, and the

general public

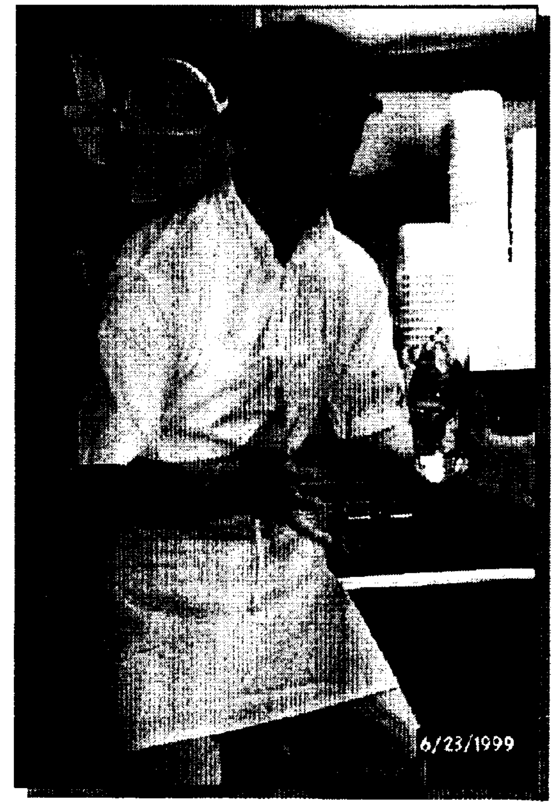
while

teaching about

microgravity science

and the benefits

of our research program.

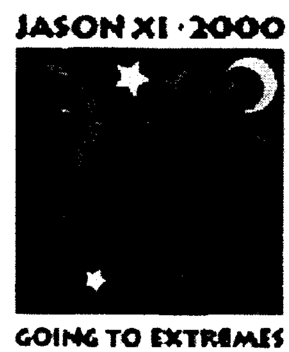


NCMR Educational Outreach Concept

- To develop a unique set of microgravity-related educational products
  - that will enable effective outreach to the K-12 community
  - that will supplement existing math, science, and technology curricula
  - that will gain broad acceptance within the educational community
  - that are created in an environment shared by educators, students, and researchers

Leveraging Educational Resources

- Cedar Point Amusement Park & Emerson Middle School
  - pilot testing of amusement park guide
  - teacher/chaperone training at Emerson for 8th grade trips
  - NCMR-led educator training at Cedar Point to start 2001
- JASON Project
  - representation on Case Western Reserve University Primary Interactive Network Site's Advisory Council
  - involves planning educator training workshops and public outreach events
- Standards Training
  - NCMR educational program staff participated in Project 2061 Benchmark training at the invitation of OEP



Educational Outreach Products

How High Is It?

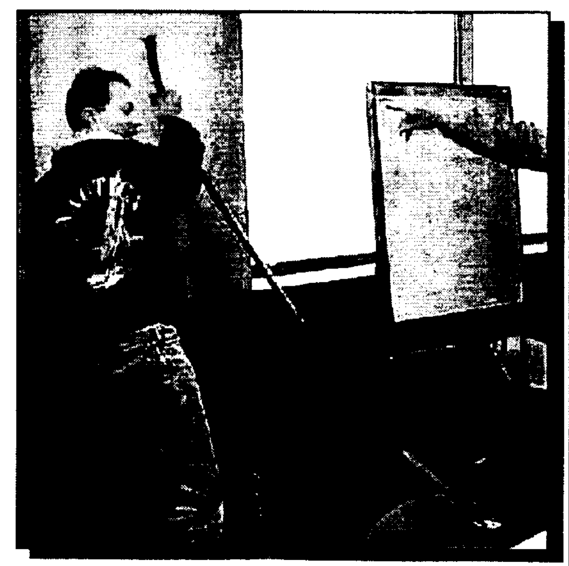
- Middle school mathematics product involving scaled distances to Earth-orbiting satellites, fractions, decimals, and percentages
- Initial activity tested on Summer 1999 math team coaches workshop
- Expanded and presented at November 1999 regional NCTM conference
- Educational Brief on hold; limited staff concentrating on higher priority projects

Glovebox Projects

- Targeted at late primary and middle school
- MSFC-produced draft text for glovebox poster being redone by NCMR
- Additional activities being developed for two February 2000 workshops (Ohio science educators and Space Center Houston ISS Educators Conference)
- Activities based on MRPO-funded investigations or on purposes for glovebox
- Compilation of activities into a teacher's guide on hold, limited staff concentrating on higher priority projects

Educational Outreach Products

- **Fall Into Mathematics**
  - Exhibit artwork for Spring 1999 National Council of Teachers of Mathematics convention
  - Supporting Educational Brief developed for initial distribution at 1999 NCTM convention
  - Poster distribution starts at 2000 NCTM convention
  - All artwork was created at Marshall based on NCMR designs
- **Educator Workshops**
  - NCMR leads approximately 10 workshops per year
  - Participation ranges from 10-30 teachers per workshop
  - Potential to reach 2,000 to 12,000 students per school year
  - Typical workshop sponsorship/location
    - Glenn Office of Educational Programs/NASA GRC
    - JASON Program/CWRU campus
    - National and regional teachers conferences/ U.S. & Canada
    - Cedar Point Amusement Park/Cedar Point & GRC



Educational Outreach Workshops

July 1999 - NASA Educators Workshop Microgravity Day

Agenda

9:00	Introduction/Logistics
9:10	Gravity, Grah-ah-vit-y! Song
	2 Quarter Drop
	Falling For Microgravity—5 Ways
9:30	Microgravity Demonstrator
10:00	Break
10:15	Water Balloons on the DC-9
10:20	Water Flows...Up? Activity
11:00	Smoke Signals Activity
12:00	Lunch
1:00	Glovebox
2:00	Tour Zero-G Facility
2:45	Tour 2.2 Second Drop Tower/Egg Drop Contest
	Seltzer Rockets
4:00	Closing Comments

Educational Outreach Efforts

- Outreach doesn't have to be painful
  - most researchers we work with seem to enjoy classroom visits
  - seek out public events associated with your areas of interest and/or professional organizations
- Investigate leveraging opportunities
  - that is, find someone else to do the hard work
  - seek out mentoring programs where you can be assigned an educator/classroom
- If you're a PI in the program, let someone know what you do
  - MRPO monitors outreach efforts, and may start requesting outreach plans in NRA proposals
  - tell your project scientist if you're involved in outreach efforts
  - seek out MRPO- or NASA- affiliated programs

21/51

MGMG #19

S-/25C4
36P

Paper Number: 6

Microgravity effects on microbiology in space laboratories

Emily S. Nelson
NASA Glenn Research Center
Cleveland, Ohio

Elizabeth Juergensmeyer
Judson College
Elgin, Illinois

Margaret Juergensmeyer
Montana State University
Bozeman, Montana

Here we present a review of the effects of residual acceleration on microorganisms in space laboratories. Residual acceleration in the microgravity environment is frequently ignored by microbiologists, although their experiments may be as sensitive to this acceleration as those designed by materials scientists and fluid physicists. Furthermore, analysis to date has been largely empirical and/or based on very simple theoretical models. As a result, the responses of single cells to the space environment are widely assumed to be taking place in "pure" microgravity. These responses vary widely and are not well understood. Some of this variation may be due to the range of microgravity conditions experienced by the organisms. In the future, as we move from visiting orbital environments to living and working there, we will undoubtedly bring microorganisms with us. It is also quite likely that the first extraterrestrial life we encounter will be single-celled organisms. Therefore, we would like to present a summary of the current knowledge base, and to challenge the space community to develop new approaches in understanding this important field.

Microgravity effects on microbiology in space laboratories

Emily Nelson
Computational Microgravity Laboratory, NASA Glenn Research Center
Emily.S.Nelson@grc.nasa.gov

Margaret Juergensmeyer
Department of Microbiology, Montana State University

Elizabeth Juergensmeyer
Department of Math and Science, Judson College, Elgin, IL

Computational Microgravity Laboratory

Microgravity Measurements Group #19

Cleveland, OH July 11-13, 2000

Glenn Research Center

Objective

Develop understanding among the biological, fluid physics, and microgravity measurement and design communities to solve open questions in biology:

- application to **long-duration spaceflight** (including **realistic** assessment of effects of **residual acceleration**)
- appreciation of **biological mechanisms underlying behavior**
- identification of the interface between fluid physics and biology in a microgravity environment
    - **buoyancy**, **sedimentation**
    - role of **convective transport**
    - bringing to bear the **powerful tools** used in the fluid physics community for solution of basic problems in the biological community
    - assessment of clinical tools for **simulating microgravity**
    - assessment and design of **experimental protocols**

2

Why study this problem?

Bacteria/microbes are present in the space environment. They:

- are **omnipresent;** some are very hardy
- exhibit unusual behaviors in:
  - **proliferation**
  - **resistance** to antibiotics and disinfectants
- give concern due to risk of **disease**
- will be useful in **management of trash and biological waste**, and in closed ecosystems

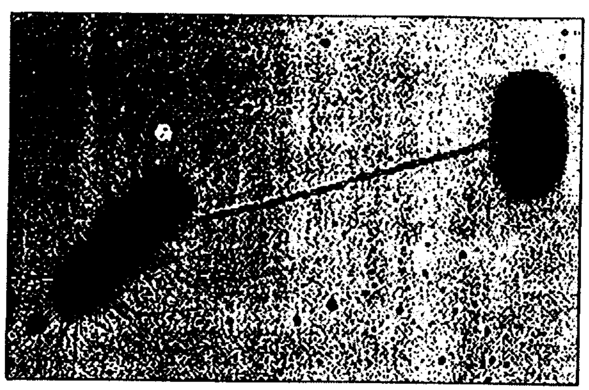
Microbial behavior in space may yield insight into their fundamental biological functions and processes, e.g.:

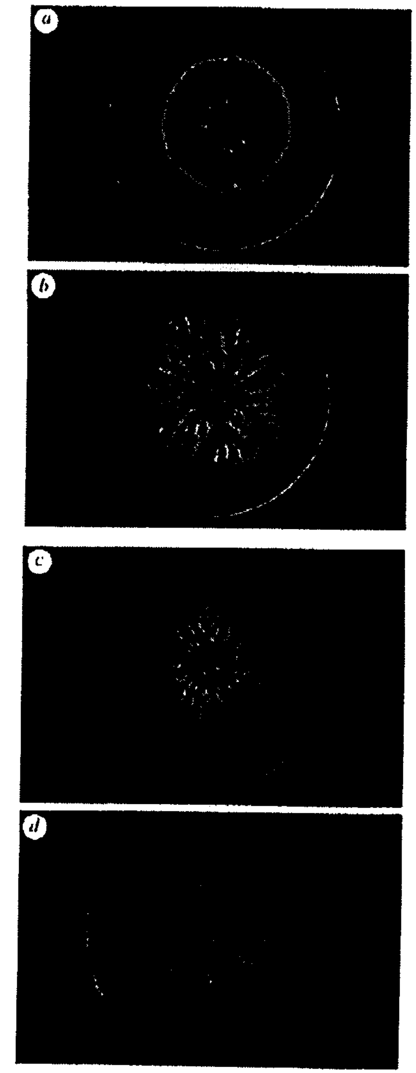
- **gravitaxis**, gravikinesis, **locomotion**
- **sedimentation**, usage of nutrients

3

Challenging questions in space microbiology

- growth rate, yield
- resistance to antibiotics and disinfectants
- graviperception
- changes in genetic recombination
- (lack of) adaptation to space environment
- interface between fluid physics and biology





Pattern formation of *Paenibacillus dendritiformis* on agar as a function of peptone concentration

(Ben-Jacob et al., 1994)

4

A need to challenge to current dogma

Axiom:

- Bacteria grow **more rapidly** and to **higher yields** in space
- Bacteria are **more resistant** to antibiotics in space

Fact:

- Bacterial growth in space is **not consistently higher** in space
- Bacterial resistance is **not consistently higher** in space

$\Rightarrow$ **The challenge is to discover:** why are bacterial proliferation and resistance different in space?

5

A review of microbial response to space

Table 2-1 Summary of Bacterial Experiments in Space

Reference	Bacterial Growth			Other Experiments			
	Length of Lag Phase	Growth Rate	Final Cell Density	Antibiotic Effectiveness	Effects of Radiation	Production of Spores and Metabolites	Miscellaneous
Zhukov-Verezhnikov, 1962					—		
Mattoni, 1968			H				L
Taylor and Zaloguev, 1978				L			
Kordium *et al.*, 1980			H				
Tixador *et al.*, 1981, 1985; Lapchine *et al.*, 1987				L			H
Ciferri *et al.*, 1986			H				H
Mennigmann and Lange, 1986	L	H	H			L	
Lapchine *et al.*, 1986, 1987, 1988; Moatti and Lapchine, 1986				L	L		
Manko *et al.*, 1987	L	L					H
Il'in, 1990				L			
Bouloc and D'Ari, 1991		—	—		—		
Pierson *et al.*, 1993			H				
Mennigmann and Heise, 1994	—	H			—	H	—
Gasset *et al.*, 1994	L	—					
Klaus, 1994; Klaus *et al.*, 1994, 1997	L	—	H	L			H
Tixador *et al.*, 1994	L	—	—	L	L		—
Horneck *et al.*, 1996					—		
Thévenet *et al.*, 1996	L						—
Kacena *et al.*, 1997; Kacena and Todd, 1997	L	—	—				
Lam *et al.*, 1999			L			H	

H - Parameter was higher on orbit. L - Parameter was lower on orbit. — - No change on orbit

6

- Brown (1997), who is the first to attempt a comprehensive analysis of steady g effect on bacterial growth

Probably the most complete listing to date in current literature

Organism	Growth rate	Yield	Medium Phase	Carrier	Duration	Cell specifics	Base medium	Additives to base medium	Temperature protocol	Fixative	Method used for cell count	# Experiments at each condition	Launch/landing delays	Time to examination	Reference	Comments
Bacillus subtilis	NC	NC	S	Mir	4 mos	ATCC 6051	Difco nutrient agar	none	Launch: 25°C Grow: <32°C Store: 4° C	none	CFU	2	N	11h	Juergensmeyer et al. (1999)	Yield; (1g: 1.4e4, 1.7e6 mg: 9.5e4, 6.5e4 CFU/ml)
	NC	NC	S	Shuttle	138 h	ATCC 6051	2% bacto-agar	5g/l glucose, Medium E	Launch: 4° C Grow: 25° C Store: 4° C*	0.2 ml of 2% glutaraldehyde	hemacytometer		N	⊘	Kacena and Todd (1997)	Fixed at 18, 30, 48, 54, 66, 96, 114 and 138h.
	NC	NC	S	Shuttle	67-288h	ATCC 6051	2% agar in medium E	some with 5 g/l glucose	Launch: 4° C Grow: 25, 37° C Store: 4° C	0.2 ml of 2% v/v glutaraldehyde	hemacytometer	8	N	⊘	Kacena et al. (1997)	No statistically significant increase in yield for µg, ground, clinorotated, horiz. Shaking table, microg.
	⊘	⊘	S	Skylab	72-88h	⊘	0.45 µm millipore filters on D-0001 nutrient agar	none	Grow: 36° C* Store: 5+-3° C	none	⊘		N	1 wk	Staehle (1978)	*Overheating of Skylab caused ambient temperature rise of app. 30 deg C for 12h. Growth pattern of space specimens showed increased height.
	⊘	+	L	Mir	60-120d	ATCC 4157	medium E	5 g/l glucose	Launch: 4° C Grow: 23+-2° C* Store: 4° C	1.5 ml 1% v/v glutaraldehyde	hemacytometer; CFU		Y	11d	Kacena et al. (1999)	*After fixing, cultures were held at 23 deg C until return to earth. Flight culture at 120 days was 170% larger than ground culture. NOTE C(t=0) not known.
	oscillated (IML-1)	+ (IML-1); NC (D-2)	L	Shuttle	>30h	⊘	minimal medium (D2); nutrient broth (IML-1)	⊘	Launch: Grow: 37° C Store: 4° C	none	optical density		N	⊘	Mennigsmann and Heise (1993)	IML-1: (Yield tripled. 1g: 15% of all cells sporulated; µg: 60% of all cells). D-2 and IML 1 found contradictory results in yield, possibly because of different growth media.
	oscillated	+	L	Shuttle	72h	⊘	growth medium	⊘	Grow: 37° C Store: 4° C	glutaraldehyde	optical density		N	⊘	Mennigsmann and Lange (1986)	D1. (g:3e7 cells/ml, 8e5 spores. µg:1e5 cells/ml, 5e4 spores). Over short term (9 hrs), space culture showed oscillatory behavior in biomass, as measured by optical density.
Candida albicans	⊘	+-	B	Shuttle (25 missions)	4-15d	throat, nose, urine, feces	N/A	N/A	N/A	N/A	CFU	144 astro-nauts	N/A	N/A	Pierson et al. (1993)	Most frequent isolate in throat swabs (increase), urine (decrease), not found in nasal swabs
	⊘	+(1g)*	B	ground-based	12mo	skin, upper respiratory tract	N/A	N/A	N/A	N/A	⊘	⊘	N/A	N/A	Zaloguev et al. (1971)	*Ground-based study on confinement effects increase after 1 mo confinement.
	⊘	+*	B	Apollo Soyuz		skin, mouth, nose, throat, groin, toes	N/A	N/A	N/A	N/A	⊘	⊘	N/A	N/A	Taylor and Zaloguev (1976)	*If present initially, it persisted through the mission, unlike other fungal species. Transmission during flight noted.
	⊘	+	B	Apollo 13-17	5-12d	skin, mouth, nose, urine, feces	N/A.	N/A	N/A	N/A	⊘	⊘	N/A	N/A	Taylor (1974)	Recovered in each Apollo 13-17 mission. This microbe would thrive under reduced competition, e.g., long-term antibiotic.
Chlamydomonas reinhardii	⊘	+	L	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	Gavrilova et al. (1992)	
	⊘	- (hyperg)*	L	centri-fuge	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	NA	NA	Tairbekov et al. (1998)	*Decreased yield with increasing g from 2g to 5g. At last stage of expt, cells lost motility and sank.
	⊘	+/NC*	L	Shuttle	M	wild (wt+); short-period mutant (s)	agar dissolved in inorganic salt medium	yeast extract; some with sodium acetate	Grow: 25°C	Lugol	hemacytometer	1?	N	16h	Mergenhagen and Mergenhagen (1989, 1987)	Biorack. *Yield doubled in acetate-supplemented wt+, but NC w/o supplement; increased by 30 (50, 1989 ppr)% in acetate-free s-.

Organism	Growth rate	Yield	Medium Phase	Carrier	Duration	Cell specifics	Base medium	Additives to base medium	Temperature protocol	Fixative	Method used for cell count	# Experiments at each condition	Launch/landing delays	Time to examination	Reference	Comments
Escherichia coli	NC	NC	S	Mir	4 mos	ATCC 10798	Difco nutrient agar	none	Launch: 25° C Grow: <32° C Store: 4° C	none	CFU	2	N	11h	Juergensmeyer et al. (1999)	Yield: (1g: 5.2e6, 3.0e6 mg: 1.1e6, 5.4e7 CFU/ml)
	NC	NC	S	Shuttle	138h	ATCC 4157	2% bacto-agar	5g/l glucose, Medium E	Launch: 4° C Grow: 25° C Store: 4° C*	0.2 ml of 2% glutaraldehyde	hemacytometer		N		Kacena and Todd (1997)	*After fixing, cultures held @Tg until mission was complete; then held at Ts for transport to investigators.) Shortened lag phase flight vs. ground. No statistically significant diff clinorotated vs. ground
	NC	NC*	S	Shuttle	M	ATCC 4157	2% agar in minimal medium E	some with 5 g/l glucose	Launch: 4° C Grow: 25, 37° C Store: 4° C	0.2 ml of 2% v/v glutaraldehyde	hemacytometer	8	N	Ø	Kacena et al. (1997)	7 Shuttle missions, 3 types of apparatus. *One of the 10 samples had a statistically significant increase in yield (STS-62). Authors think it to be anomalous.
		+	L	Mir	L	ATCC 4157	minimal medium E	5 g/l glucose	Grow: 23+-2° C* Store:	1.5 ml 1% v/v glutaraldehyde	hemacytometer; CFU		Y	11d	Kacena et al. (1999)	Flight culture at 120 days was 90% larger than ground culture. (Note: there was a large variance in ground controls, though). C(t=0) unknown
		+*	L	clino-rotated	Ø	Ø	Ø	Ø	Ø	Ø	Ø	Ø	N/A	N/A	Klaus et al. (1998)	*On ground-based clinostat in functional motionlessness. Yield app doubled on clinostat relative to static.
	NC/-*	+	L	Shuttle	12h-14d	ATCC 4157	minimal medium E	some with 5g/l glucose or ribose	Grow: 20+-1° C, 37+-1° C	100% ethanol (33%v/v)	hemacytometer optical density	38	Y	Ø	Klaus et al. (1997, 1994)	*Growth rate: decrease, clinical observation. Yield: doubled (µg: 7.8e8+-3.7e8 cells/ml; 1g: 4.4e8+-2.9e8 cells/ml)
	NC	NC/+*	L	Shuttle	S	K12: GC2852, PhB405, MH225; 200 or 1000 clones per well initially	M63 minimal medium	0.4%w/v glucose; 1 µg/ml thiamine, some with NaCl**	Launch: 4° C Grow: 37° C Store: 4° C	750 µg/ml chloramphenicol in ethanol	optical density	2-6	N	3-25d	Thevenet et al. (1996)	IML-2. *Motile strain GC2852 showed no significant difference in yield or growth rate. Nonmotile strain PhB405 showed a significant increase in flight.
	NC/+*	NC/+*,*	L	Shuttle	10h	1: LMC 561 (growth studies; glucose-starved) 2: ATC 25922 (antibiotic activity)	1: M9 minimal medium 2: peptone water (Difco)	1: aneurine, MgSo4, glucose, NaCl, pH 7.4 2: pepton 1%, NaCl 0.5%, pH 7.2	Launch: 5° C (till day 8 of mission) Grow: 37° C Store: 5° C	1: 0.5% formaldehyde, post-fixation osmium tetroxide; 2: 35% glutaraldehyde in 0.5M cacodylate buffered solution at pH 7.4	CFU; optical density; electronic particle counter		N	30h	Tixador et al. (1994, 1995), Gasset et al. (1994)	IML-1, Biorack. *Growth rate: NC w/o antibiotic; increase w/antibiotic as antibiotic concentration increased. **Yield: NC w/o antibiotic; w/antibiotic, increase observed.
	NC	NC	L	Biocos-mos 2044	24h	1: GC2852 (growth studies); 2: GC4415 (SOS induction)	1: M63 minimal medium 2: LB broth	1: 40 µg kanamycin/ml and glucose or glyc-erol at 4 concen-trations 2: 10 µg tetracycline/ml	Launch: 37° C Grow: 37° C Store: 4° C	1: none 2: chloramphen- icol, final concentration 200 µg/ml	optical density; Coulter count	1-3	N	2-7d	Bouloc and d'Ari (1991)	Glucose promotes anaerobic growth; glycerol supports aerobic growth. No effect on yield seen for either nutrient in space or on the ground. No effect of hyperg @3.5g either.
	NC	NC	L	Shuttle	3h	C-1091 & C-411 (conjugation); C-1055 (trans-duction); HB101 (transforma-tion)	Ø	glycerol, final concentration 15% v/v	Launch: -15° C Grow: 37° C Store: 4° C	none	viable cells	1?	N	36h	Ciferri et al. (1986)	Biorack. Cultured for 24|48 after return. Says there is an increase in yield in space, but it's not drastic, and actually goes down in one case
	Ø	+	L	Shuttle	24h	ATCC 25922	API 10M	yeast extract	Launch: 4±1° C* Grow: 37±1° C* Store: 5±1° C	after recovery, glutaraldehyde, followed by osmium tetroxyde	CFU	1-4?	N	1d	Lapchine et al. (1987, 1986)	D1. 100x more CFUs in space

Organism	Growth rate	Yield	Medium Phase	Carrier	Duration	Cell specifics	Base medium	Additives to base medium	Temperature protocol	Fixative	Method used for cell count	# Experiments at each condition	Launch/landing delays	Time to examination	Reference	Comments
Escherichia coli (cont'd)		+*	L	Biosat-ellite II	44h	C-600	L broth (millipore filtered)	buffer, nitrate	Launch: on ice Grow: not controlled	none	CFU; Coulter count	8-20	N	⊘	Mattoni et al. (1971), Mattoni (1968)	*Note: due to curtailment of mission, culture was still in log phase at retrieval. Anaerobic growth. Radiation effect of 3 radiation levels undetectable. CFU count inconsistent with cell count on flight cultures.
	NC/- (hyperg)*	NC/- (hyperg)*	L	centri-fuge	48h	⊘	⊘	⊘	Grow: 25-35° C	none	CFU	1	N/A	⊘	Montgomery et al. (1963)	*Very high g values relative to 1g. Growth rate: decrease @110,000g, but NC @1000g. Yield: decrease @110,000g NC @1000g, @110,000g
	⊘	+/-*	B	Shuttle (25 crews)	4-15d		N/A	N/A	N/A	N/A	CFU	-	N/A	N/A	Pierson et al. (1993)	*A frequent isolate in nasal swabs (decrease during flight), urine (increase during flight).
	⊘		B	Apollo Soyuz		skin, mouth, nose, throat, groin, toes	N/A	N/A	N/A	N/A	N/A	⊘	N/A	N/A	Taylor and Zaloguev (1976)	Found regularly in the groin of one Apollo crew member and in upper respiratory tract of 2 other crew members.
Paramecium tetraurelia	+	+	L	Shuttle	120h	wild strain 82b	sterilized straw medium	*Aerobacter aerogenes*	Launch: 9° C* Grow: 22±0.5° C	35% glutaraldehyde in cacodylate buffer 0.2M	dissecting microscope	16	N	⊘	Richoilley et al. (1988)	Examination for cell count followed recovery. Fixed at 47, 71, 96, 118h. Centrifuged 1g, microg had similar populations.
	⊘	- (hyperg)*	L	fast clinostat	48h	wild strain 82b	sterilized straw medium	*Aerobacter aerogenes*	Grow: 27±0.25° C	none?	cell count	15	N/A		Ayed et al. (1992)	Yield increased relative to static controls after 48h. Examines yield for accelerations from 50-110 rpm (does not correlate them to acc, however). Max at 80-90 rpm.
	⊘	- (hyperg)*	L	fast clinostat	3-4d	wild strain 82b	sterilized straw medium		Grow: 25° C	none?	dissecting microscope	15	N/A	N/A	Planel et al. (1989, 1990)	*Decreased yield in hyperg. Also noted dependence on tube diameter, prob. due to gravity gradient. At lower g (1.4-2g), yield decreased with increasing rot'n rate (and decreasing dist from rot'n axis). Yield decreased with increasing tube dia.
	⊘	+ (1g)*	L	balloon	19, 22h	variety 4, mating type VII, one cell initially per chamber (homozygous)	sterilized straw medium	*Enterobacter aerogenes*	Grow: 25±0.1° C	none?	dissecting microscope	?	N/A	N/A	Planel et al. (1983)	In Cytos incubator. Increase with cosmic rays in 1g. (balloon flight). Fixed at t=0, 10, 22h. Rotated (simulated microg) and static cultures on the ground had same cell pop after 3 days.
	⊘	+	L	Salyut 6	96h	variety 4, mating type VII, one cell initially per chamber (homozygous)	sterilized straw medium	*Enterobacter aerogenes*	Launch: 8±1° C Grow: 25±0.1° C Store: ° C	85% formalin 10% anhydrous ether 5% acetic acid	dissecting microscope	8-16	N	⊘	Planel et al. (1982, 1981)	Cytos I, M. Cytos M: fixed at 20h, 44h, 50h, 56h, 60h, 80h, 96h. At 56h, flight cultures were 54% higher than controls. Cytos I: fixed at 12 96h every 12h. At 72h, space cultures were 98% larger than ground controls.
Pseudomonas aeruginosa	+	+	S	Mir	L	ATCC 27853	Difco nutrient agar	none	Launch: 25° C Grow: <32° C Store: 4° C	none	CFU	2	N	11h	Juergensmeyer et al. (1999)	A big increase in growth rate. Yield: 1g: 4.9e4, 2.2e4 mg: 7.5e6, 2.0e8 CFU/ml
	+/-*	+/-	LB	Mir	120d	ATCC 27853	distilled water	none		16% $Na_2S_2O_3$	CFU	8	N		Marchin (1999)	*On Mir, without disinfectant, CFUs doubled at 30 days, halved at 60 days, less than ground cultures than 90 days, at app the same value at 110 days. Bacteria were grown for 30, 60, 90, 110d and fixed 24h afterwards

Organism	Growth rate	Yield	Medium Phase	Carrier	Duration	Cell specifics	Base medium	Additives to base medium	Temperature protocol	Fixative	Method used for cell count	# Experiments at each condition	Launch/landing delays	Time to examination	Reference	Comments
Pseudomonas aeruginosa (cont'd)	+*		L	ground-based			BHI or PBW								McFeters et al. (1991)	*At 1g/simulated μg, increase in growth rate in low-nutrient Brain Heart Infusion broth relative to phosphate-buffered water. No data on yield.
0	⊘	+	B	Apollo 13-17	5-12d	skin, mouth, nose, urine, feces	N/A	N/A	N/A	N/A	N/A		N/A	N/A	Taylor (1974)	Spread to the feet of all three crewmembers during an Apollo 15.
Staphylococcus aureus	+	+	S	Mir	4 mos	ATCC 6538P	Difco nutrient agar	none	Launch: 25° C Grow: <32° C Store: 4° C	none	CFU	2	N	11h	Juergensmeyer et al. (1999)	Growth rate doubled. Yield: g: 8.0e4, 2.5e5 mg: 1.3e10, 7.0e8 CFU/ml)
	⊘	+	B	Shuttle (11 missions)	5-16d	nose, throat, urine, feces	N/A	N/A	N/A	N/A		57 astro-nauts	N	N/A	Pierson et al. (1993, 1996)	Most frequent isolate from throat & nasal swabs, also in urine.
	⊘	NC	B	Apollo Soyuz		skin, mouth, nose, throat, groin, toes	N/A	N/A	N/A	N/A	N/A	⊘	N/A	N/A	Taylor and Zaloguev (1976)	No postflight increase in incidence for the project as a whole, unlike previous studies. Transmission during flight noted.
	⊘	+	B	Apollo 13-17	5-12d	skin, mouth, nose, urine, feces	N/A	N/A	N/A	N/A	N/A		N/A	N/A	Taylor (1974)	Recovered repeatedly from Apollo 13, 14, 15 astronauts, once each from Apollo 16, 17. Intercrew transfer is common during spaceflight (perhaps due mostly to confinement). Postflight incidence of recovery was greater than preflight.
	⊘	+*	B	ground-based confine-ment	15 d	oral cavity and pharynx	N/A	N/A	N/A	N/A	N/A		N/A	N/A	Zaloguev et al. (1971)	*Ground-based study of long-term human confinement for 15 days, monitored for 1 yr. Largest variation noted was an increase in staphylococcal flora.
Tetrahymena pyriformis	+	⊘	L	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	Irina et al. (1989)	
	⊘	+ (hyperg)*	L	centrifuge	1-4d	? 600 cells/ml, 4ml	sterile 2% proteose-peptone medium (Difco)	none	Grow: 27° C	none	Coulter count	20	N/A	N/A	Planel et al. (1989)	*Yield increased as g increased from 1.4-4g, but a threshold was reached @10g (cells died after 2 days @10g). Influence of angular speed at const g was not significant, as it was for *P. tetraurelia* (note size diff).
	+	⊘	L	Cosmos-1887, 2044	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	N/A	N/A	Tairbekov et al. (1998a)	on Cosmos-1887, Cosmos 2044.
	⊘	- (hyperg)*	L	centrifuge	⊘	⊘	⊘	⊘	⊘	⊘	⊘	⊘	NA	NA	Tairbekov et al. (1998)	*Centrifuge expt showed decreasing yield with increasing g. With increasing g from 2g to 5g, the entry into stationary phase began earlier at a lower population density. At last stage of expt, cell size diminished.

⊘=no information

+= increase
-=decrease
NC=no change
N/A=not applicable

L= liquid
LB= liquid and beads
S= solid
B= human body

Microbial growth in microgravity

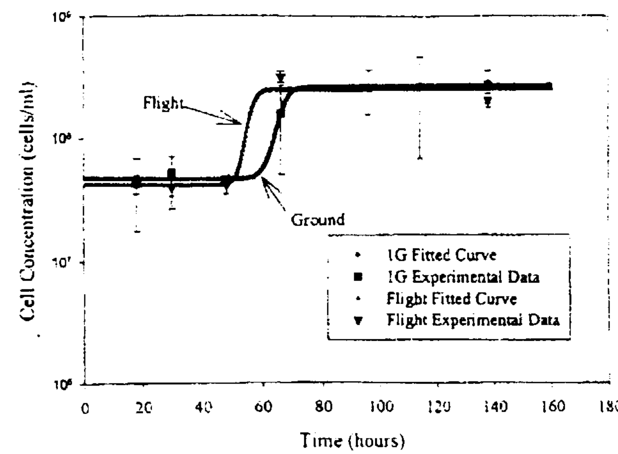
Cell specifics: species, strain, individual, initial concentration, starved/well-fed, ...

Medium: liquid|solid, type of liquid|solid, ...

Nutrients added/withheld:
(an)aerobic growth, minimal medium/optimal growth conditions, ...

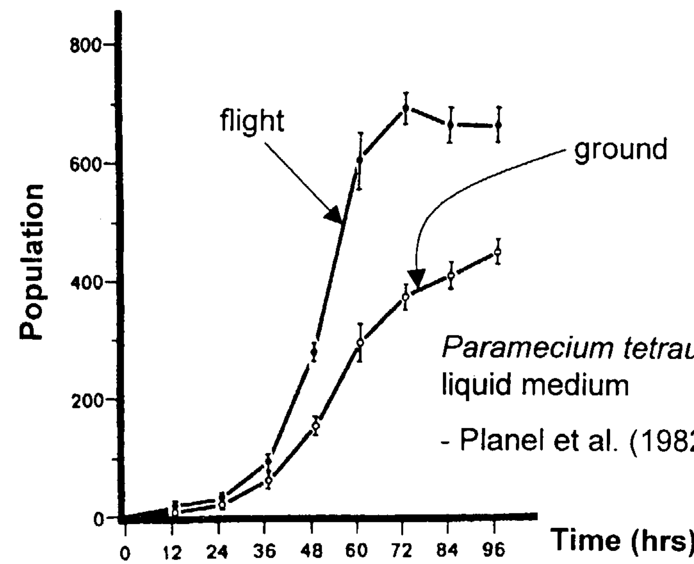
Experimental protocols:
temperature, presence of other microbes, type of fixative and when it was added, delay between fixing and examination, method used for cell counts ...

Microgravity environment: carrier, duration, external events, ambient radiation, ...



Escherichia coli on agar

- Kacena and Todd (1996)



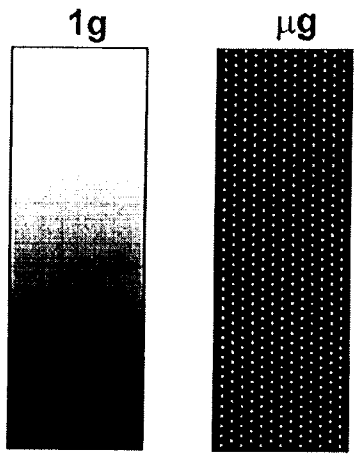
Paramecium tetraurelia in liquid medium

- Planel et al. (1982)

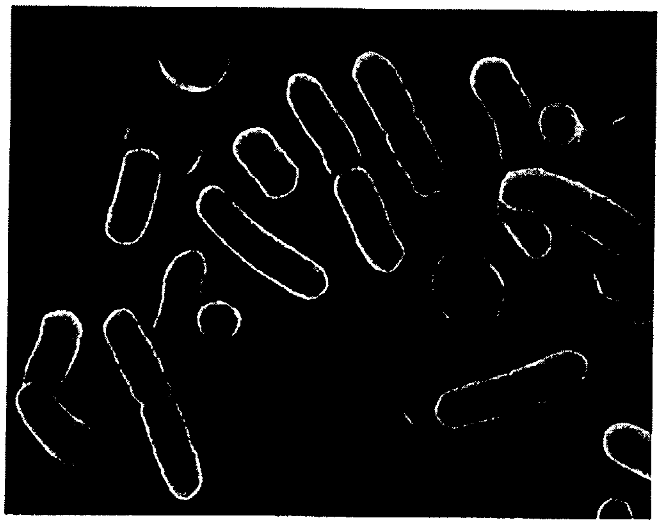
11

Microbes in suspension

Cartoon of microbial distribution at:



E. coli



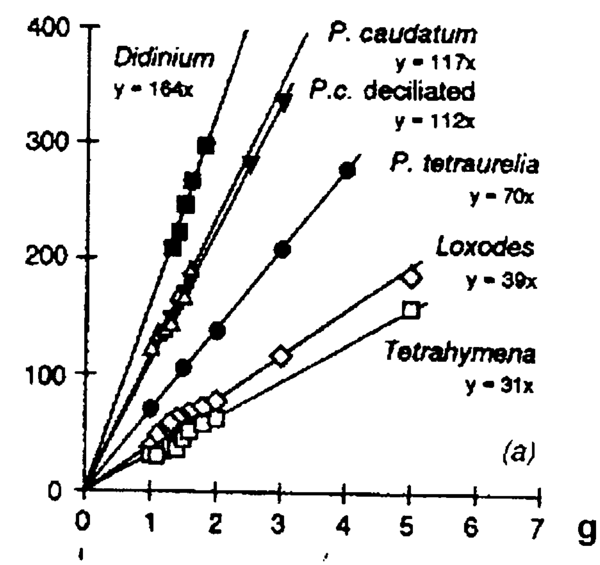
Many bacteria of interest are rod-shaped; others are cocci or other shapes. Some tend to cluster; some do not.

At 1g, nonmotile microbes tend to **sediment** toward the bottom of a vessel. At μg, cells tend to remain in **suspension**. This may lead to more optimal growth conditions at certain stages of the growth process through better access to nutrients.

One important piece to add to the picture is the microbe's **motility**, which can affect bioconvective flows, e.g., *Tetrahymena*. A mean swimming velocity can be estimated; the orientation of the motion may be predicted through a balance of gravitational torque (due to nonuniform internal mass distribution) and viscous drag on the organism.

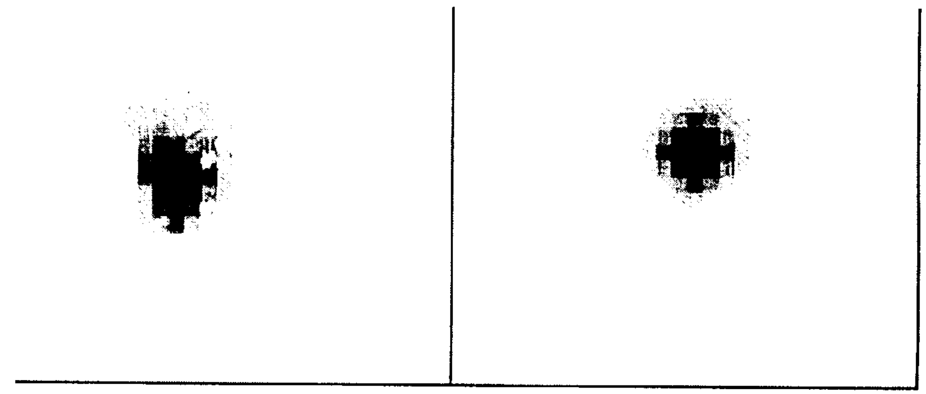
12

Microbes in suspension (cont'd)



Gravitational effects on sedimentation for nonmotile microbes

- Nagel et al. (1997)



1g 0g

Gravitational effects on medium composition surrounding a bacterium

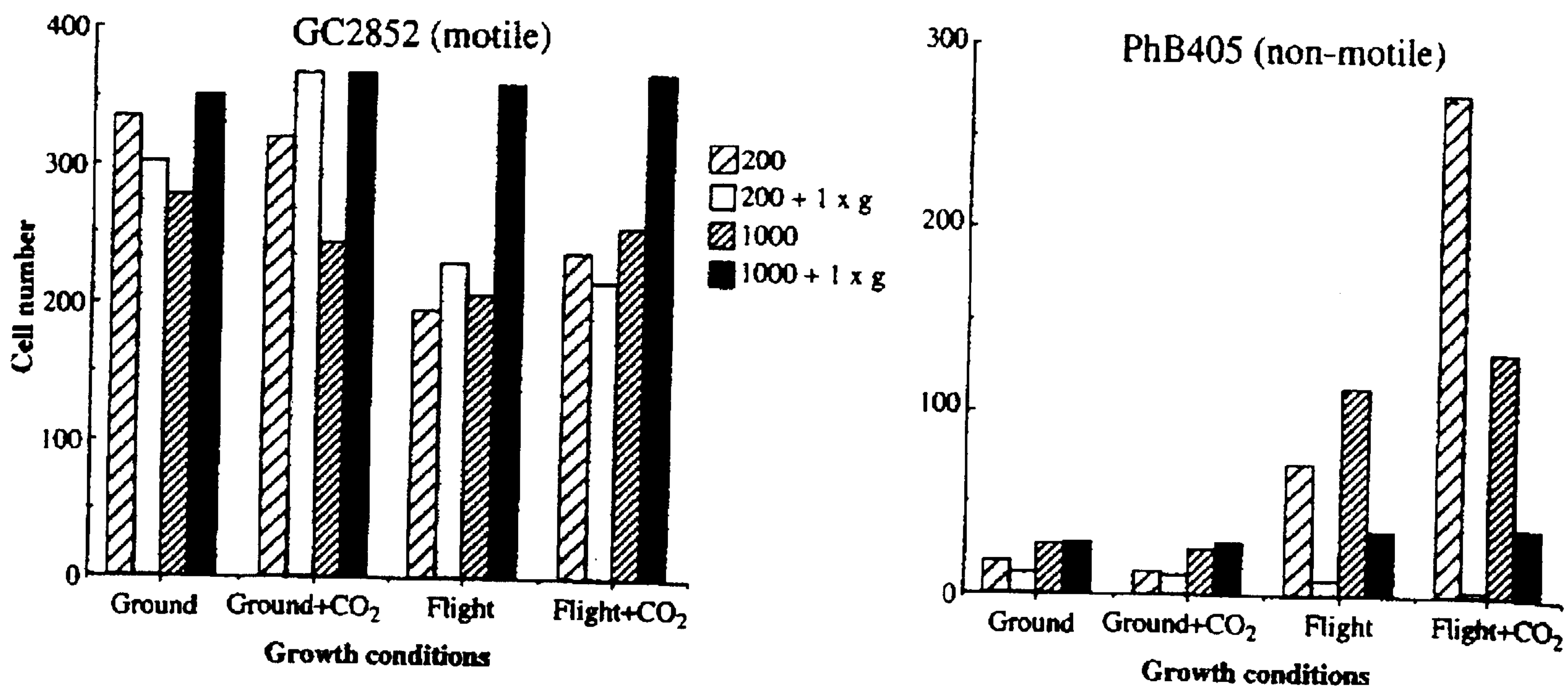
http://www.colorado.edu/engineering/BioServe/anti-prod.html

- Klaus, D.M. (1998).

⇒ NOTE: Need to incorporate microbial locomotion in transport models as well as sedimentation, particularly in suspension-dominated growth

13

Microbes in suspension (cont'd)



Microbial yield after 9 hrs of μg on the Shuttle is a function of the **strain** of *E. coli* used, **additives** present (here Na_2CO_3), **initial concentration** of microbes and **acceleration** magnitude

- Thévenet et al. (1996)

14

Summary of microbial growth conclusions

- More **care** must be taken in comparing experiments and reaching broad conclusions
- Depending on the microbe, the medium, and the specifics of the environment and experiment protocols, bacteria show **markedly different growth characteristics** in the space environment
- More sophisticated **numerical modeling** coupled with experiment could prove invaluable
- Systematic exploration of the role of **residual acceleration** may prove important

Organism	Medium phase	Cell specifics	Carrier	Duration	Yield in µg (untreated)	Medium	Antibiotic applied	Detection method	ampicillin (1)	cephalothin (1)	oxacillin (1)	penicillin G (1)	gentamycin (2)	kanamycin (2)	streptomycin (2)	tetracycline (2)	chloramphenicol (3)	erythromycin (3)	colistin (polymyxin E) (4)	polymyxin B (4)	rifampicin (5)	iodidinated resin	nalidyxic acid	Comments	Reference
Bacillus subtilis	S	ATCC 6051	Mir	4 mos	NC	Difco nutrient agar	PF	ZOI (visual)	-	-		-	-	-	+-	-	+-	-	-	-	+-			Significant increase in variance in space. Susceptible ground culture became clinically resistant to rifampicin (only species of 4 tested to do so)	Juergensmeyer et al. (1999)
	S	⊘	Skylab	L		0.45 µm millipore filters on D-0001 nutrient agar	PF	ZOI (visual)	-	NC		+			-	-	-			-			-	*Saw increased colony diameter in space.	Staehle (1976)
	L	⊘	fast-rotating clino-stat	S	+ (IML-1); NC (D-2)	minimal medium nutrient (D2); nutrient broth (IML-1)	N/A							+										Note differing yields possibly due to different liquid media.	Mennigmann and Heise (1993)
	[illegible]	⊘	Shuttle	M	NC	⊘	⊘									-								Dried spores on Spacelab.	Nagaoka et al. (1996)
Escherichia coli	S	ATCC 10798	Mir	4 mos	NC	Difco nutrient agar	PF	ZOI (visual)	-	-		+	-	-	+-	-	-	-	-	-	+			Least change in variance in flight of the 4 species tested. If resistant (susceptible) on ground, more resistant (susceptible) in µg (only species to show this pattern).	Juergensmeyer et al. (1999)
	LB	B. strain NP4	Shuttle	20h?	⊘	distilled water	DF	CFU														-		USML-1 in FPA. No untreated µg control for yield count. Pentaiodide resin was more effective than triiodide both on the ground and in µg. Biofilm on resin bead surface noted in one experiment. Temp: Launch 4 deg C, Grow: 22 deg C, Store: 4 deg C. Quenched with 10% S_2O_3 +NB.	Marchin et al. (1997)
	L	ATCC 25922	Shuttle	M	NC	peptone water (Difco) with pepton 1%, NaCl 0.5% pH 7.2	DF								+*									*Dihydrostreptomycin.	Tixador et al. (1994, 1995), Gasset et al. (1994)
	L		Shuttle	24h	+	yeast extract	DF	MIC (color)											+					D1. Yield w/o antibiotic was >1e8 cell/ml for all cases. At inhibitory concentrations of colistin, 100x more CFUs formed in space than on earth.	Lapchine et al. (1986, 1987)
	L	astronaut skin	Salyut 7	24h	⊘	API 10M	DF	MIC (color)						+					+					CYTOS 2. No yield info. More pronounced µg antibiotic effect than for *S. aureus*. Resistance did not persist in postflight cultures.	Lapchine et al. (1986), Tixador et al. (1985a, b)
	[illegible]	astronaut intestines	Salyut 7	⊘	⊘	crew	PF	MIC	NC				NC	NC	NC	+	NC		NC					The majority of the cultures isolated from the crew postflight were resistant to tetracycline, although no preflight cultures had this resistance.	Il'in (1989)

Organism	Medium phase	Cell specifics	Carrier	Duration	Yield in µg (untreated)	Medium	Antibiotic applied	Detection method	ampicillin (1)	cephalothin (1)	mecillin (1)	penicillin G (1)	gentamycin (2)	kanamycin (2)	streptomycin (2)	tetracycline (2)	chloramphenicol (3)	erythromycin (3)	colistin (polymyxin E) (4)	polymyxin B (4)	rifampicin (5)	iodidinated resin	nalidyxic acid	Comments	Reference
Pseudomonas aeruginosa	S	ATCC 27853	Mir	4 mos	+	Difco nutrient agar	PF	ZOI (visual)	NC	-		NC	-	NC	NC	+	NC	+	+	-	-			Yield: 1g: 4.9e4, 2.2e4 mg: 7.5e6, 2.0e8 CFU/ml. Changes in resistance were small; variance in µg comparable to that on earth.	Juergensmeyer et al. (1999)
	LB	ATCC 27853	Mir	24h	+-	distilled water	DF	CFU														+		Untreated yield: CFUs doubled at 30d, halved at 60d, comparable to ground control at 110d. On ground with pentaiodide resin beads, less than 10 CFUs at all times; on Mir, <10 at 30 days, numbers began to increase subsequently.	Marchin (1999)
	B	astronaut	Shuttle	M	⊘	N/A	DF*; PF**									+*								One crewmember had a urinary tract infection and high numbers of *P. aeruginosa*. In-flight treatment with tetracyclin proved ineffective. Treatment with Coly-Mycin B was initiated 2 days after return to earth and was effective.	Taylor (1974)
Staphylococcus aureus	S	ATCC 6538P	Mir	4 mos	+	Difco nutrient agar	PF	ZOI (visual)	+-	+-		-	-	+-	+-	+-	+-	+-	NC	-	+-			Mir. Yield: g: 8.0e4, 2.5e5 mg: 1.3e10, 7.0e8 CFU/ml). Only species to show both clinically and statistically significant change in resistance to more than one antibiotic; became clinically resistant to penicillin G; variance increased dramatically in space	Juergensmeyer et al. (1999)
	L	astronaut skin	Salyut 7	M	⊘	API 10M	DF	MIC (color)			+						+	+						CYTOS 2. No yield info. 5 antibiotic concentrations surrounding MIC. Less significant effect than for *E. coli*.	Tixador et al. (1985a, b)
	B	pharynx and oral cavity	ground-based confinement	15d	⊘	human body	DF*	⊘				+**				+**								*Ground-based study of long-term human confinement. Largest variation in the oral cavity and pharynx was in the composition of staphylococcal flora. **Pathogenic staphylococci showed decreased resistance to some antibiotics although the general trend was toward increased resistance to penicillin, tetracycline group antibiotics and to levomycetin. Response to other antibiotics was unaffected.	Zaloguyev et al. (1971)

⊘=no information

Medium phase: B=Body D=Dried spores L=Liquid LB=liquid with beads

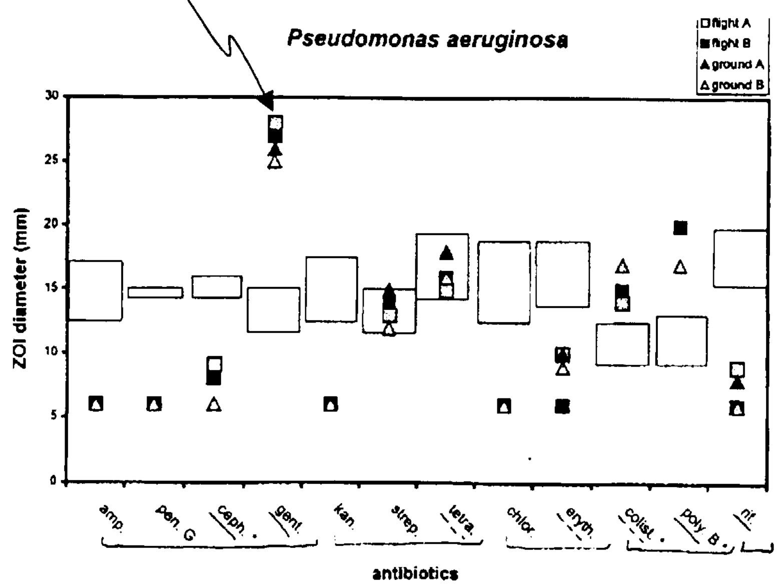
MIC=Minimal inhibitory concentration ZOI=zone of inhibition

(1) inhibits cell-wall synthesis. (2) inhibits protein synthesis by binding to 30S ribosomal subunit. (3) inhibits protein synthesis by binding to 50S ribosomal subunit (4) disrupts plasma membrane; (5) inhibits DNA-dependent RNA polymerase

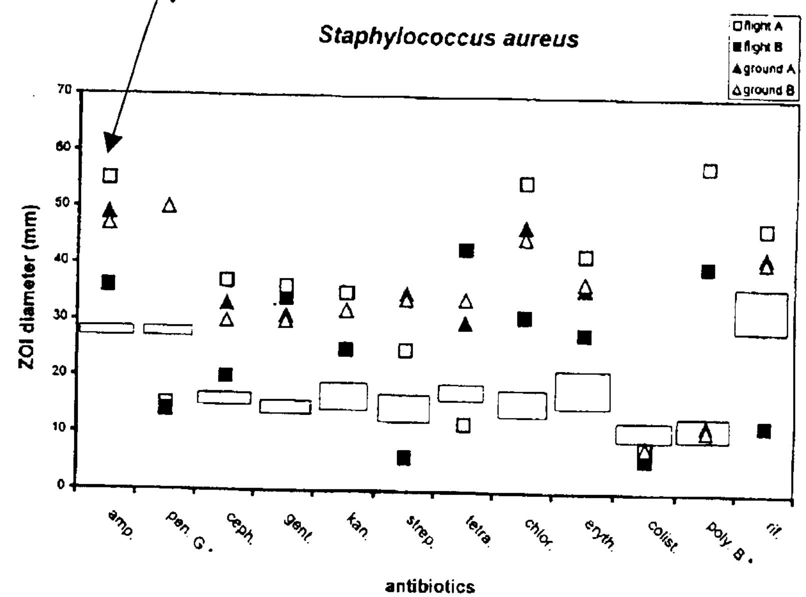
DF: During Flight
PF: Post Flight

Microbial resistance

If resistant (susceptible) on earth, then more resistant (susceptible) in space



Much larger variance in space; effectively brackets ground control



A function of microbe/antibiotic pair (Juergensmeyer et al., 1999)

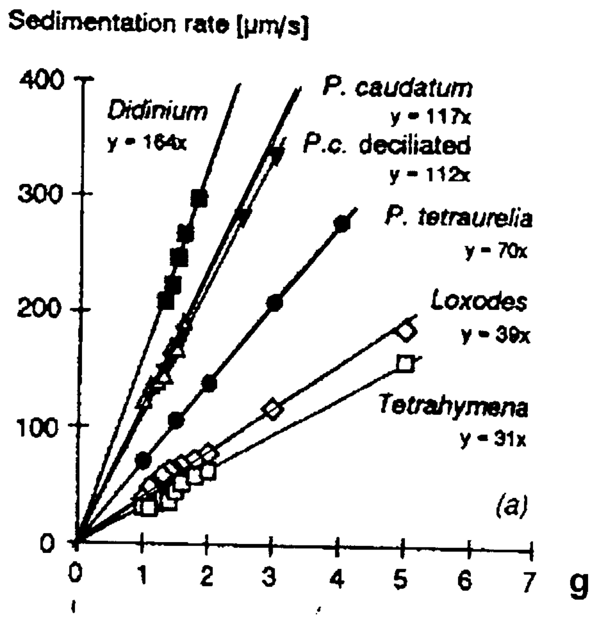
18

Summary of microbial resistance in space

- **No standard protocol** for assessing microbial resistance
  - addition of antibiotic/disinfectant during or post flight, levels
  - duration of microgravity growth, as well as medium composition, base state of organism, temperature protocol, delay in examination, ...
  - requires good statistical design of experiment
- **Wide variation** among species/antibiotic combinations
  - some exhibited greatly increased variance in space (effectively bracketing ground controls) - although some did not (Juergensmeyer et al., 1999)
  - 1 of 4 species became more resistant (susceptible) to 12 antibiotics in space if resistant (susceptible) on ground (Juergensmeyer et al., 1999)

19

Graviperception

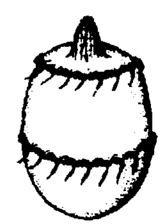


Gravitational effects on sedimentation for nonmotile microbes

- Nagel et al. (1997)

• In the absence of light, many cells exhibit negative **gravitaxis** (orient their front ends opposing gravity) so that they tend to swim up. What makes that happen? (Hint: it's not buoyancy)

• Some cells also appear to exhibit **gravikinesis** (gravitational regulation of velocity)

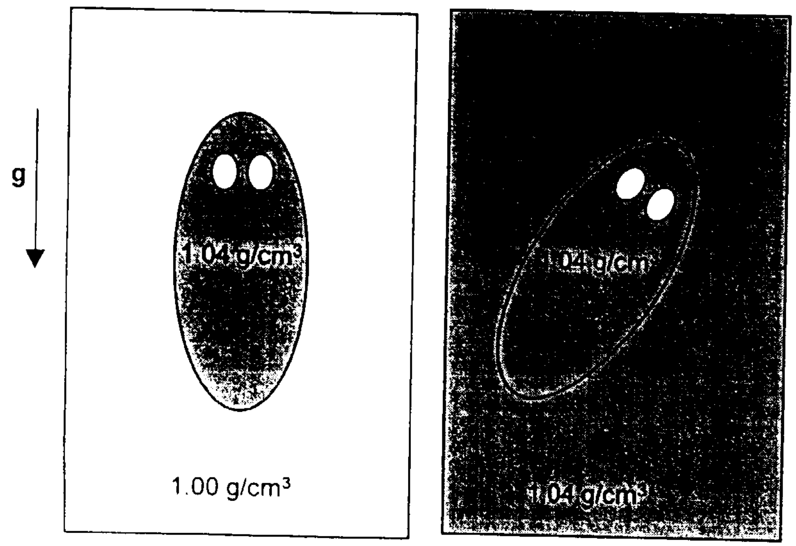


Didinium

Paramecium

Loxodes

Gravitaxis



Paramecium

Müller vesicles (nodules of $BaSO_4$) of ρ~4.5 g/cm^3

Loxodes

- Hemmersbach and Häder (1999)

In density-adjusted media, *Paramecium* loses its orientation w.r.t gravity...

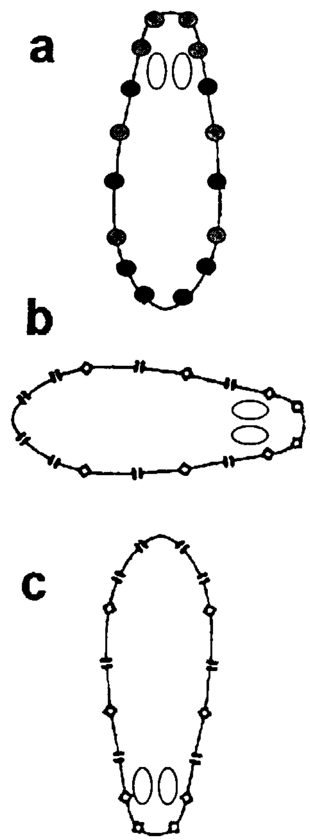
... but *Loxodes* does not

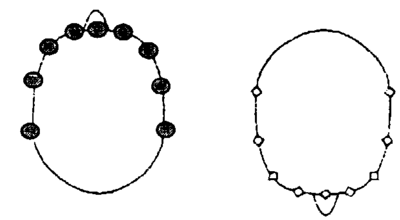
In response to a step change in gravity, *Paramecium* adjusts its course smoothly to compensate...

<u>Other possible factors</u>: light, oxygen concentration, heavy metal ions, temperature, culture age, temperature, UV radiation

21

Gravikinesis





Didinium

- Machemer et al. (1992)

Mechanosensitive ion receptor channels

- Ca^{2+} (depolarizing $\Rightarrow$ decreased ciliary beating)
- K^{+} (hyperpolarizing $\Rightarrow$ increased ciliary beating)

For both microbes, downward swimming is decreased by gravikinesis. For *Paramecium*, upward swimming is enhanced.

- Hemmersbach and Häder (1999)

Paramecium

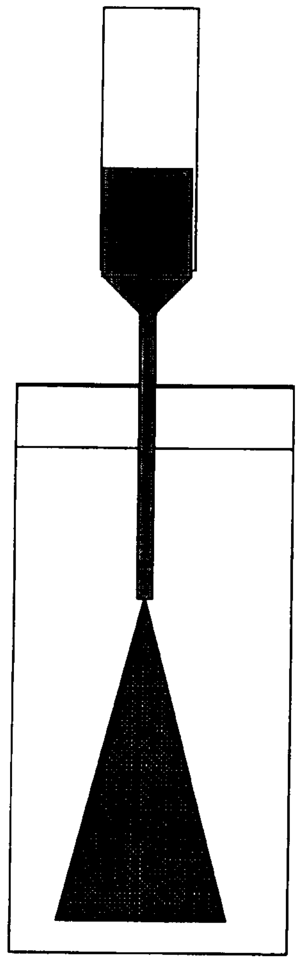
22

Search for common ground between fluid physics and microbiology

What can we learn from each other? Some facets of some experiments in microbiology are grounded in fluid transport. Although there is little work in this area from the fluids side, there is much opportunity for coordination, e.g.:

- Achieving optimal **mixing** in liquid suspensions
- Assessing **effects of residual acceleration** in liquid suspensions due to mismatch in microbe/medium density, weight distribution in microbe, and local density gradients
- Assessing **clinorotation/centrifugation** as a tool for simulating microgravity/hypergravity
- Modeling **transport through membranes** with local concentration gradients

Mixing



During injection

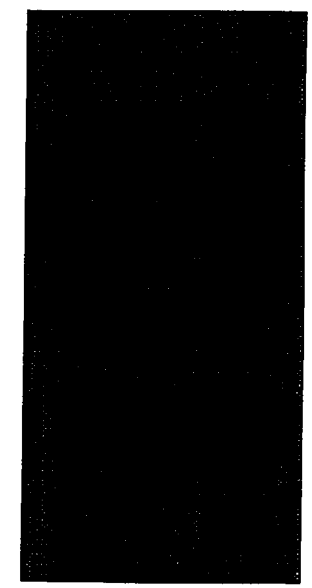
Goal: Achieve a homogeneous distribution of microbes or other additive in a fluid medium

Current state of the art: Hope for the best

Can we do better? Is it best to:

- Inject quickly or slowly?
- Inject at a particular location(s)?
- Shake the container afterward?

⇒ For this problem, it's particularly important to optimize mixing from the outset...



After injection

24

Mixing: Injecting fluid into a chamber

Momentum of injected fluid dominates the distribution of the inoculant

MOST LIKELY

- Panton (19)

Jet flow: spreading characteristics will be f(D, ρ, v, μ, chamber geometry)

POSSIBLE

- Batchelor (19)

Vortex ring: f(D, ρ, v, μ, M, t, chamber geometry)

=> NOTE: Simple experiment with dye in water can give a good idea of initial chamber mixing for typical microbiological systems (ex. *E. coli* in 0.5 ml water with 5e5 cells/ml injected into 3.5 ml water ~ pure water for this piece of the puzzle)

25

Fluid mechanics trick

Blooming jet

Axial/helical frequency at jet exit=1.7-2.3

- Juvet and Reynolds (1989)

Sensitivity to residual acceleration

- To date:
  - Limited experimental work on microbial growth in response to **vibration** exists.
  - Mixed results on using centrifuge or clinostat to mimic **steady g** effects.
- A next logical step:
  - Effects of **bulk fluid transport** can be modeled with current codes with appropriate source/convective terms
  - **Microscale effects** can be added to include:
    - effect of microbe's **weight**, **mass distribution** and **shape factor**, **locomotion**
    - effect of **density gradients** caused by nutrient depletion/waste formation

=> To date, no systematic studies have been done, incorporating all of the relevant physics, for acceleration tolerance assessment!

27

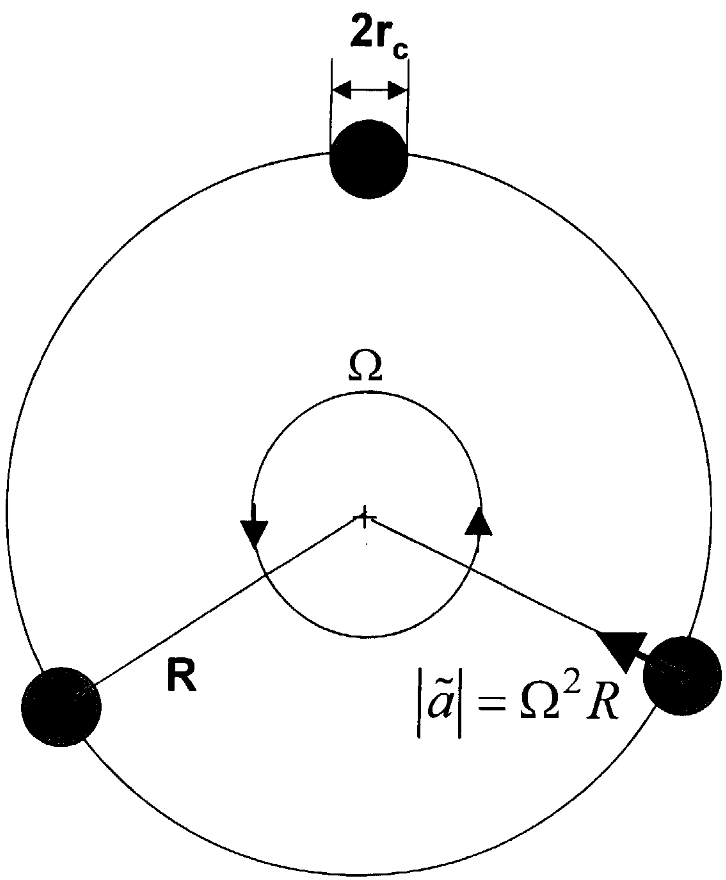
Simulated gravity through use of centrifuges and clinostats

In order to assess acceleration thresholds and their effects, centrifuges and clinostats have been used to simulate an artificial gravity field, with mixed success:

- space and ground-based centrifuges
- clinostats

While they may be an effective tool for microgravity comparison in some cases, they may be more complicated to analyze in others.

Clinorotation $\neq \mu g$



$$\vec{a}_{net} = \tilde{a} + \tilde{g}$$

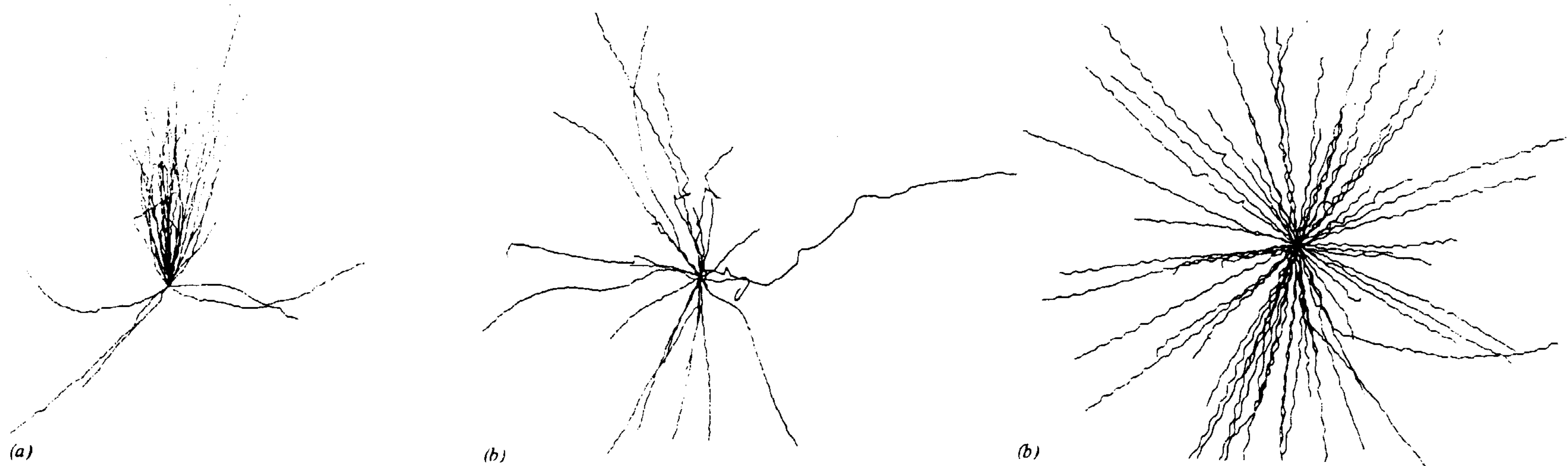
The acceleration acting on a fluid is the vector sum of all accelerations, so that in a clinostat:

- **g** is still present
- orientation of a_{net} changes continuously over a cycle
- in solid-body rotation, fluid at the center of the experimental chamber has no net motion (in the Lagrangian frame)
- across the chamber, a gravity gradient is imposed since R varies (Planel et al., 1990)

29

Clinorotation (cont'd)

Tracks of *Euglena gracilis* in 1g, μg and simulated μg



1g **μg** **clinostat**

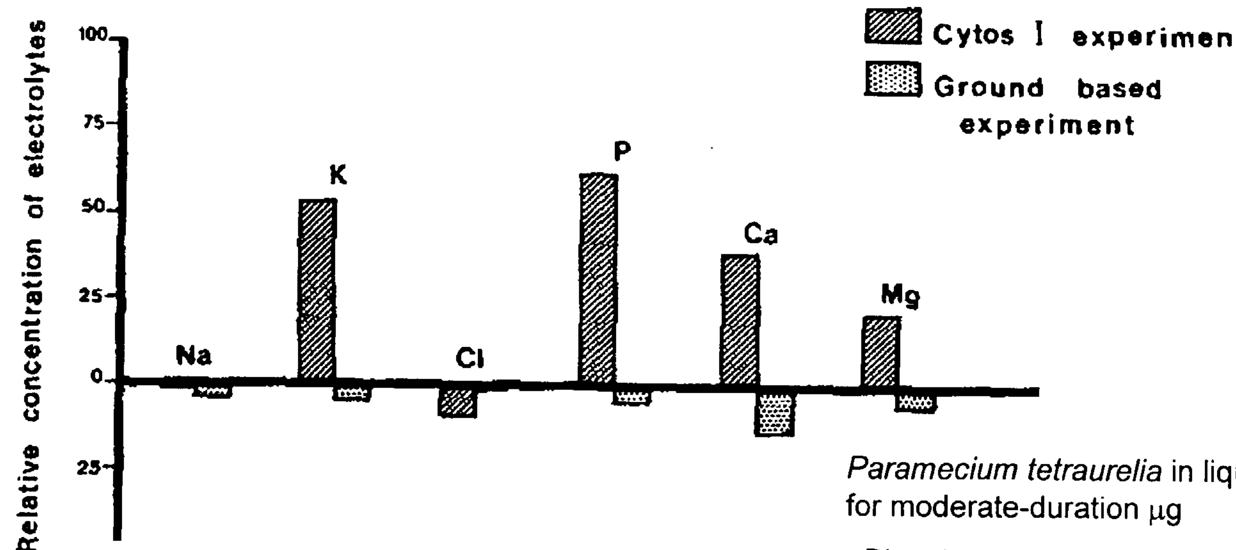
- Vogel et al. (1991)

In some situations, the clinostat reproduces microgravity results quite well, but in others, it fails miserably. The challenge is to understand why.

30

Other problems of relevance

- Transport through and near **membranes**:
  - differences in composition of extracellular fluid in space



Paramecium tetraurelia in liquid medium for moderate-duration μg

- Planel et al. (1981)

  - effects of composition gradients and gravity on convective flows (Schatz et al., 1994)

- **Liposome formation** in microgravity yields larger vesicles (Classen and Spooner, 1996)

- Some direct analogies to **protein crystal growth**

31

Conclusions

A systematic approach to space microbiology requires expertise in many disciplines

⇒ this makes it a challenge, <u>but</u> there are common areas where we can learn from each other

32

Bibliography

Batchelor, G.K. *"An introduction to fluid dynamics."* Cambridge University Press (1967).

Ben-Jacob, E., O. Schochet, A. Tenenbaum, I. Cohen, A. Czirok and T. Vicsek. *"Generic modeling of cooperative growth patterns in bacterial colonies."* **Letters to Nature 368**:46-49 (1994).

Bouma, J.E. and D.L. Pierson. *"Combined effects of simulated microgravity and multistrain interactions on population dynamics of a constructed microbial community."* **SAE Paper 981605** (1998).

Beischer, D.E. and G.S. Cowart. *"Exposure of Escherichia coli to low frequency vibrations."* **NASA CR 109494** (1970).

Brown, R.B. *"Effects of space flight, clinorotation, and centrifugation on the growth and metabolism of Escherichia coli."* PhD Thesis. University of Colorado (1999).

Claassen, D.E. and B.S. Spponer. *"Liposome formation in microgravity."* **Advances in Space Research 17**:151-160 (1996).

Cogoli, A. and F.K. Gmünder. *"Gravity effects on single cells - Techniques, findings and theory."* **Advances in Space Biology and Medicine 1**:183-248 (1991).

Fukui, K. and H. Asai. *"Negative geotactic behavior of Paramecium caudatum is completely described by the mechanism of buoyancy-oriented upward swimming."* **Biophys J 47:**479 (1985).

Hemmersbach, R. and D.-P. Häder. *"Graviresponses of certain ciliates and flagellates."* **FASEB J Supp 13**:569-575 (1999).

Horneck, G., H. Bücker and G. Reitz. *"Long-term survival of bacterial spores in space."* **Advances in Space Research 14**:41-45 (1994).

Juergensmeyer, M.A., E.A. Juergensmeyer and J.A. Guikema. *"Long-term exposure to spaceflight conditions affects bacterial response to antibiotics."* **Microgravity Sci Tech 12:**41-47 (1999).

Kacena, M. and P. Todd. *"Growth characteristics of E. coli and B. subtilis cultured on an agar substrate in microgravity."* **Microgravity Sci and Tech 10:**:58-62 (1997).

Klaus, D.M. *"Microgravity and its implications for fermentation biotechnology."* **Trends in Biotechnology 16**:369-373 (1998).

Lebert, M. and D.-P. Häder. *"Negative gravitactic behavior of Euglena gracilis can not be described by the mechanism of buoyancy-oriented upward swimming."* **Advances in Space Research 24:**851-860 (1999).

Machemer, H., R. Bräucker, K. Takahashi, and A. Murakami. *"Short-term microgravity to isolate graviperception in cells."* **Microgravity Sci Tech 5:**119-123 (1992).

33

Bibliography (cont'd)

Nagel, U., D. Watzke, D-Ch Neugebauer, S. Machemer-Röhnisch, R. Bräucker and H. Machemer. *"Analysis of sedimentation of immobilized cells under normal and hypergravity."* **Microgravity Sci Tech 10:**:41-52 (1997).

Panton, R.L. *"Incompressible flow."* 2nd ed, John Wiley and Sons (1996).

Planel, H., G. Richoilley, C. Caratero, R. Tixador, A. Caratero and G. Gassett. *"Effects of angular speed in responses of Paramecium tetraurelia to hypergravity."* **Microgravity Sci Tech 3**:107-109 (1990).

Planel, H., R. Tixador, Y. Nefedov, G. Grechko and G. Richoilley. *"Effects of space flight factors at the cellular level - Results of the Cytos experiment."* **Aviation, Space and Environmental Medicine 53**:370-374 (1982).

Planel, H., R. Tixador, G. Richoilley, R. Bassler, E. Monrozies, I.U. Nefedov and G. Gretchko. *"Space flight effects on Paramecium tetraurelia aboard Salyut 6 in the Cytos I and Cytos M experiments."* **Advances in Space Research 14:**95-100 (1981).

Schatz, A., R. Reitstetter, A. Linke-Hommes, W. Briegleb, K. Slenzka and H. Rahmann. *"Gravity effects on mmembrane processes."* **Advances in Space Research 14**:35-43 (1994).

Taylor, G. R. *"Recovery of medically important microorganisms from Apollo astronauts."* **Aerospace Medicine 45:**824-828 (1974).

Taylor, G. R. and S. N. Zaloguev. *"Medical microbiological analysis of Apollo-Soyuz test project crewmembers."* **NASA-TM-X-58180** (1976).

Thévenet, D., R. D'Ari and P. Bouloc. *"The SIGNAL experiment in BIORACK: Escherichia coli in microgravity."* **J Biotechnology 47:**:89-97 (1996).

Tixador, R., G. Gasset, G., B. Eche, N. Moatti, L. Lapchine, C. Woldringh, P. Toorop, J.P. Moatti, F. Delmotte and G. Tap. *"Behavior of bacteria and antibiotics under space conditions."* **Aviation, Space, and Environmental Medicine 65**:551-556 (1994).

Vogel, K., R. Hemmersbach-Krause, C. Kuehnel and D.-P. Haeder. *"Swimming behavior of the unicellular flagellate, Euglenagracilis, in simulated and real microgravity."* **Microgravity Sci Tech 5**:232-237 (1993).

Zaloguev, S.N., T.G. Utkina and M.M. Shinkareva. *"The microflora of the human integument during prolonged confinement."* In the **Proceedings of the Life Science and Space Research IX,** COSPAR 13th Plenary Meeting, Open Meeting of Working Group 5, Leningrad, USSR, May 20-29:55-59 (1970).

57/34

513567
35 p

20010197 19

Paper Number: 7

On the evaluation of the overall disturbances induced by g-jitter on fluid physics experimentation in the ISS

Rudolfo Monti & Rafael Savino
Università degli Studi di Napoli
Napoli, Italy

This paper summarizes a number of numerical results for the evaluation of the thermo-fluid-dynamic response of Fluid Physics experiments to the microgravity environment prevailing on the International Space Station (ISS).

In previous works the present authors pointed out that quasi steady (residual-g) and periodic (g-jitter) accelerations may be important sources of convective disturbances during fluid and material science microgravity experimentation. One of the key results of these studies shows that, at sufficiently high frequencies, the velocity oscillates around a non-zero average value with the g-jitter period (t), and the scalar quantities (temperature and/or species distributions) are also made up by a steady plus an oscillatory contribution. For the typical g-jitter prevailing in a large part of the frequency spectrum of the ISS, the amplitudes of the oscillation of the temperature (or concentration) distortions are small compared to the steady, time-averaged distortions, arising from thermovibrational effects (related to the non-zero average component of the velocity field). This fact proves to be of a fundamental advantage for the numerical evaluation of the overall effect of many simultaneously acting accelerations, since it can be simply computed (i.e. with less computation time) by solving only the time-averaged form of the field equations (Gershuni formulation).

In this paper different study cases (that show a large sensitivity to vibration accelerations) have been identified and numerical simulations have been carried out to extend the initial model for single frequency oscillation to the multi-frequency g-jitter environment of the Space Station (also in the presence of a quasi steady residual-g field).

The numerical simulations are carried out considering recent predictions for the ISS accelerations and solving both the full Navier-Stokes equations with a time-dependent body force (that give the "exact" instantaneous time-dependent flow) and the time-

averaged field equations, containing all the g-jitter terms (that identify the environment of the ISS) grouped in a single parameter.

It is shown that the overall "time-averaged" disturbances of the thermo-fluid-dynamic field, in the presence of the typical microgravity environment of the ISS, can be simply evaluated assigning as input to the CFD code a single sinusoidal (equivalent) g-jitter based on the overall vibrational Rayleigh number (in the time-averaged formulation).

According to the present results, ISS should be seen as an ensemble of MG platforms, due to the substantial differences (in the convective disturbances) encountered by an experimental facility when located inside different modules of the ISS (US Lab, COF).

ON THE EVALUATION OF THE OVERALL DISTURBANCES INDUCED BY G-JITTER ON FLUID PHYSICS EXPERIMENTATION IN THE ISS

R. MONTI, R. SAVINO

Università degli Studi di Napoli "Federico II"
Dipartimento di Scienza e Ingegneria dello Spazio "Luigi G. Napolitano"
P.le V.Tecchio 80, 80125 Napoli (Italy)

WORK SUPPORTED BY ESA

19th Microgravity Measurements Group Meeting
11-13 July , 2000/ Cleveland, OH

SUMMARY

This work summarizes a number of numerical results for the evaluation of the Thermo-Fluid-Dynamic (TFD) response of Fluid Physics experiments to the Microgravity Environment (MGE) prevailing on the ISS

Three main issues are addressed:

1) Preparation of numerical codes for the computation of convective disturbances induced by g-jitter

2) Definition of a "lumped equivalent g-jitter" (over the entire g-jitter spectrum) criterion for the evaluation of the "time-averaged" most relevant disturbances

3) Effect of residual-g, g-jitter and cell orientation for typical experiments located at different ISS locations (US Lab, COF).

DIRECT INTEGRATION OF FULL SET OF EQUATIONS VERSUS TIME-AVERAGE FORMULATION

Previous works at the University of Naples pointed out that, for the typical g-jitter spectra of the ISS, the amplitudes of the oscillations of the temperature (or concentration) distortions are small compared to the time-averaged distortions (with respect to the pure diffusive "0-g" conditions)

A reference study case has been identified and numerical simulations have been carried out to show that the time-averaged TFD fields can be simply computed (i.e. with much less computation time) by solving only the time-averaged form of the field equations (Gershuni formulation)

The numerical check consists in solving both the full Navier-Stokes equations with time-dependent accelerations (that give the "exact" instantaneous time-dependent flow) and the time-averaged field equations, and to compare the results

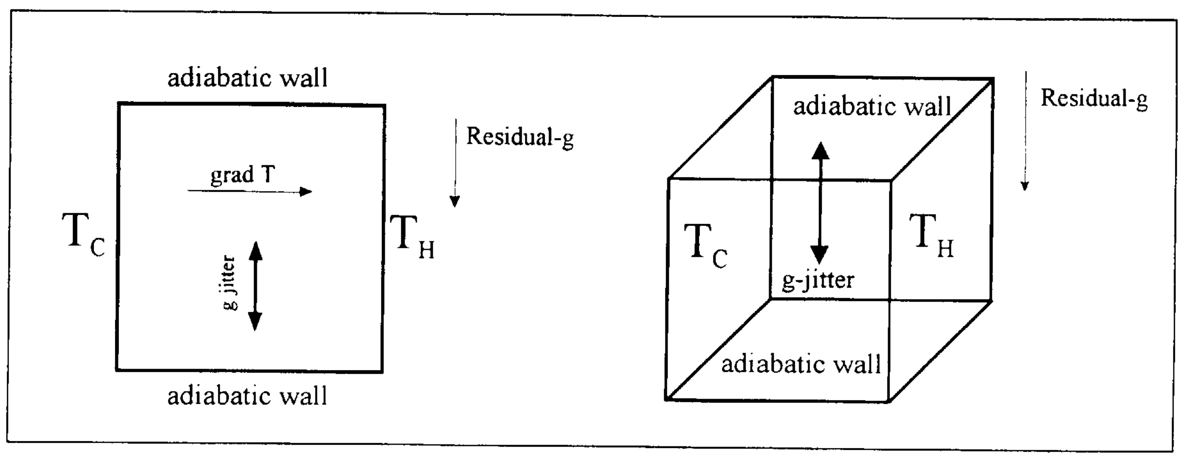
REFERENCE STUDY CASE FOR THE EVALUATION OF THE DISTURBANCES INDUCED BY THE ISS MGE

A closed cubical test cell of the Fluid Science Laboratory (side 6[cm]), filled with a liquid with low kinematic viscosity (silicone oil with with ν=0.65 [cs]).

Two opposite walls are maintained at different temperatures (ΔT=60K). The other walls are rigid and insulated.

Sinusoidal vibrations (F=3Hz, amplitude=$10^4 \mu g$, see NIRA 99) are applied in different directions (direction orthogonal to the temperature gradient is the worst situation, corresponding to the maximum temperature disturbances with respect to the diffusive case).

Oil 0.65 cs	
β_T= 1,3000E-03	(1/K)
λ= 1,2000E-01	(W/m/K)
μ= 5,7200E-04	(Kg/m/s)
Cp= 2,0000E+03	(Joule/Kg/K)
ρ_0= 8,8000E+02	(Kg/m^3)
Residual_g= 1,6000E-05	(m/s^2)
L= 6,0000E-02	(m)
ΔT= 5,0000E+01	(K)
α= 6,8182E-08	(m^2/s)
ν= 6,5000E-07	(m^2/s)
t_{rif}= 5,2800E+04	(s)
Pr= 9,5333E+00	
Rag= 5,0688E+03	

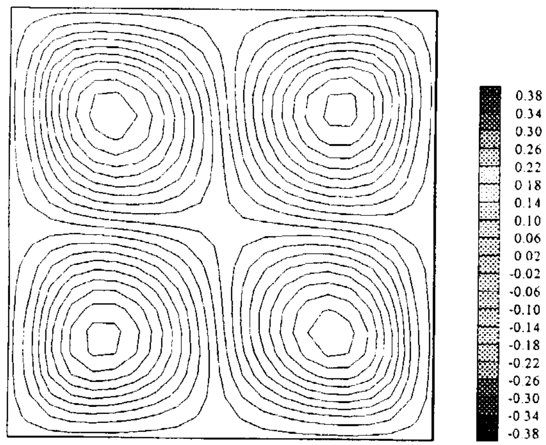


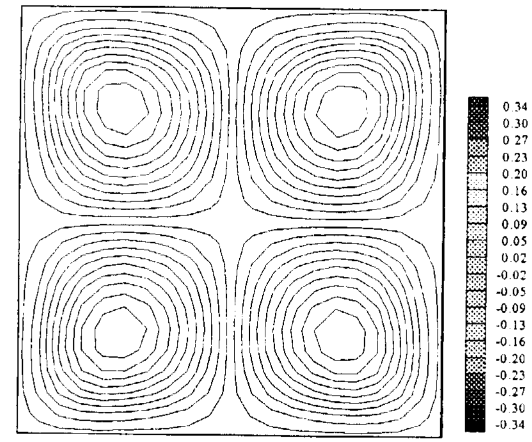
G-Jitter (frequency=3 Hz, amplitude=10mg)
Time = 60 (s)

DIRECT FORMULATION

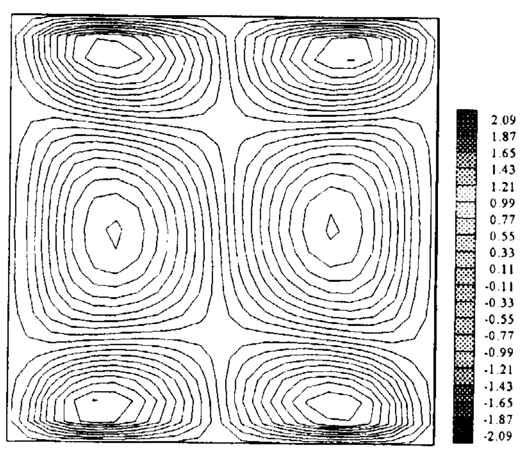
TIME-AVERAGED FORMULATION

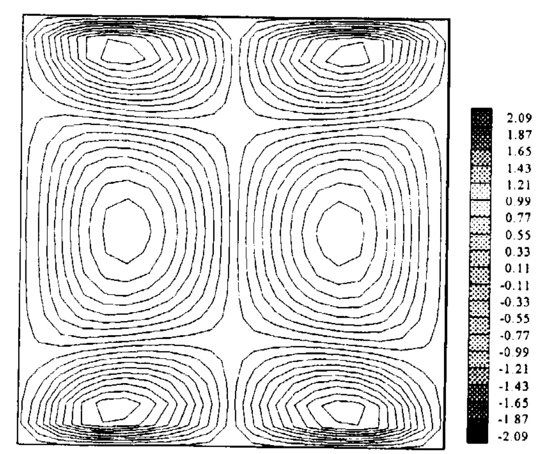
G-Jitter





Non Dimensional Stream Function

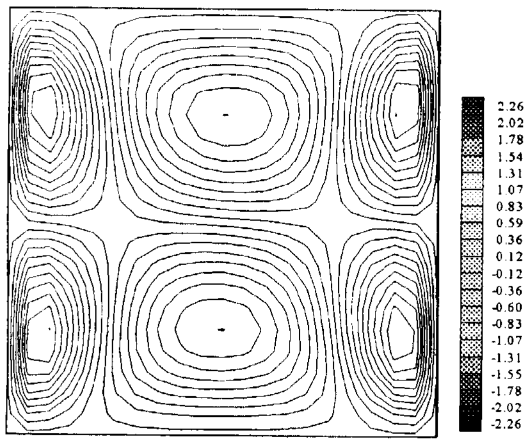




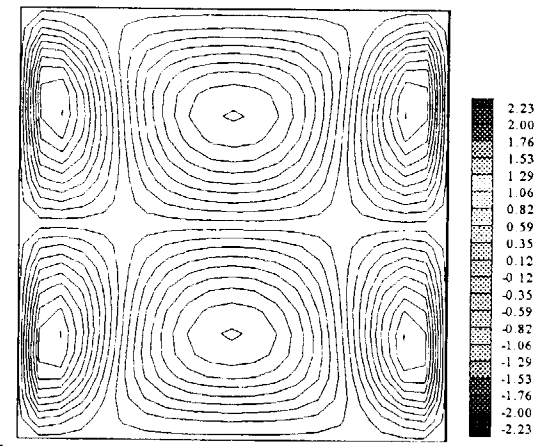
Non dimensional X-velocity

Time = 60 (s) cont'd

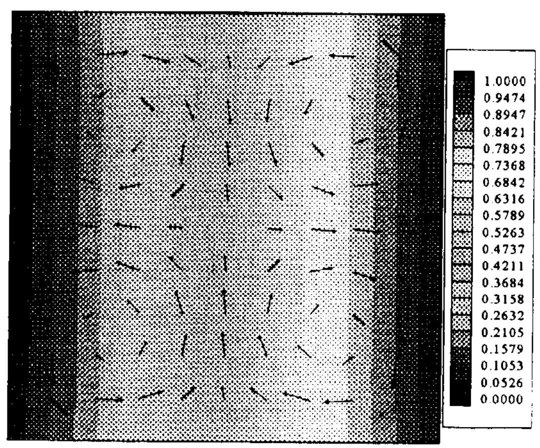
DIRECT FORMULATION | **TIME-AVERAGED FORMULATION**

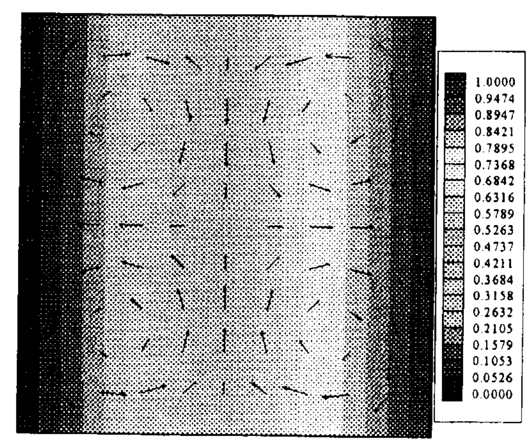


G-Jitter



Non dimensional Y-velocity



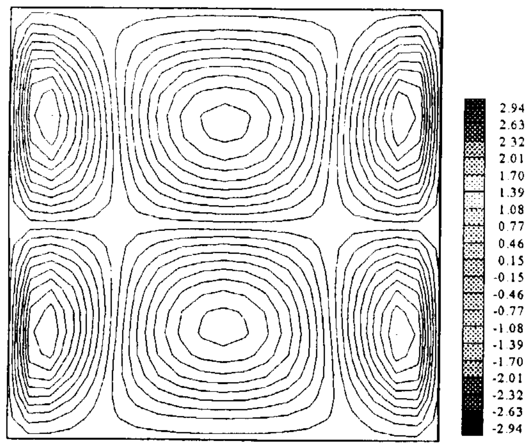


$(V_{max}/V_{\alpha} = 2.5)$ | Non Dimensional Temperature | $(V_{max}/V_{\alpha} = 2.25)$

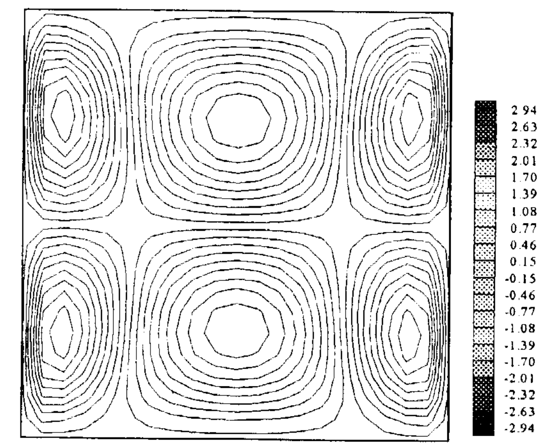
Time = 600 (s) cont'd

DIRECT FORMULATION

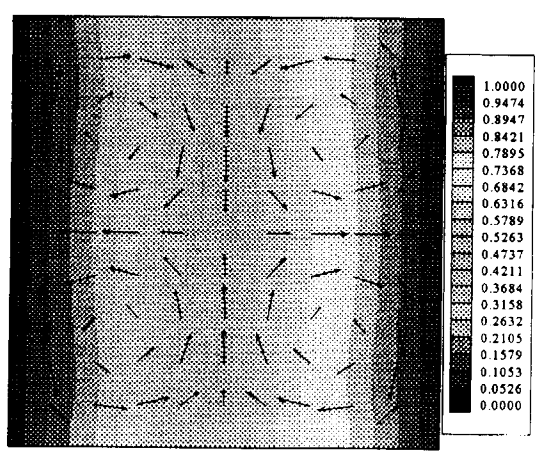
TIME-AVERAGED FORMULATION

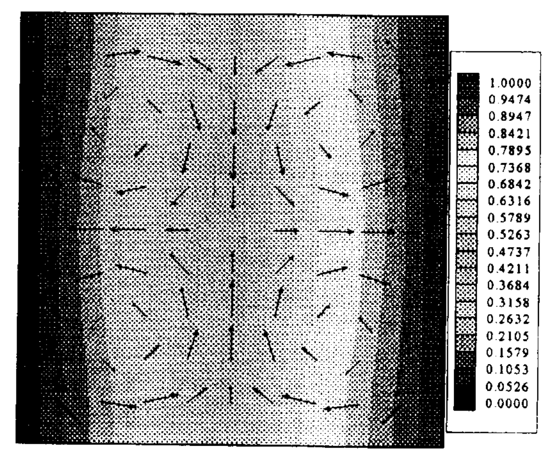


G-Jitter



Non dimensional Y-velocity





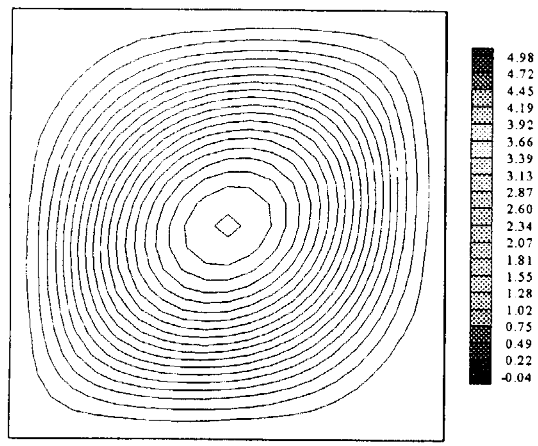
$V_{max}/V_{\alpha}=2.99$

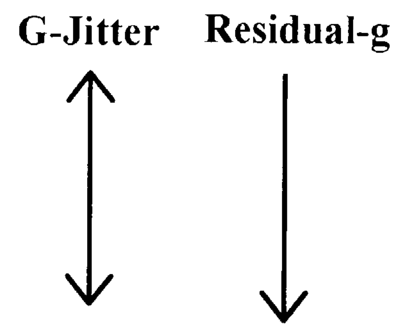
Non Dimensional Temperature

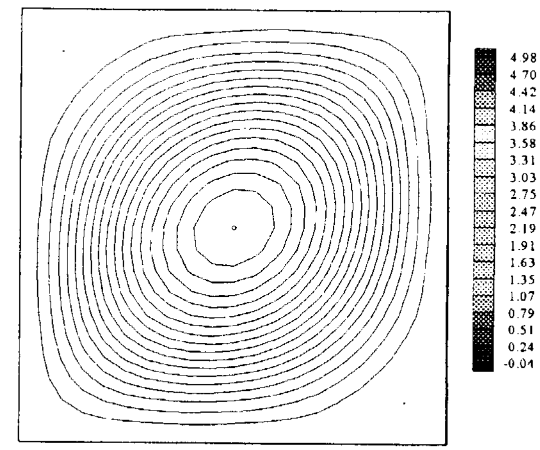
$V_{max}/V_{\alpha}=2.97$

RESIDUAL-G (1.0 μg)+G-JITTER (3Hz)
$\alpha_g = \alpha_j = 90$ (deg) -- Time = 600 (s)

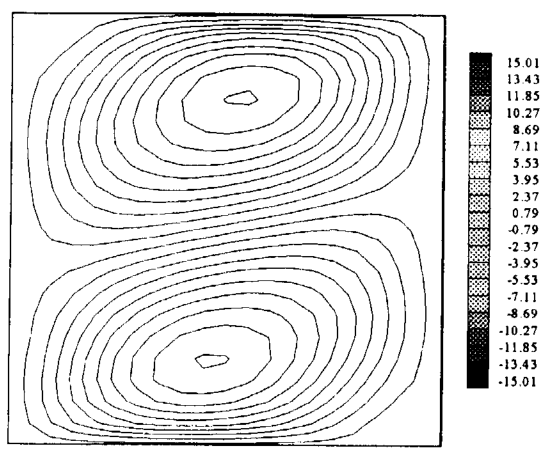
DIRECT FORMULATION **TIME-AVERAGED FORMULATION**

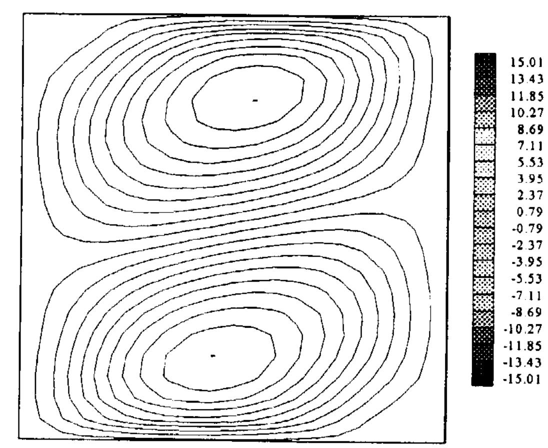






Non Dimensional Stream Function

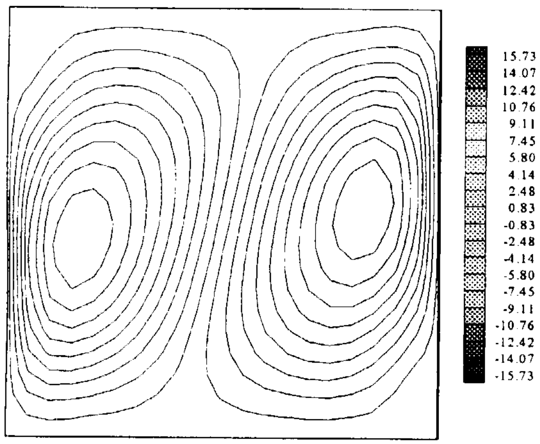




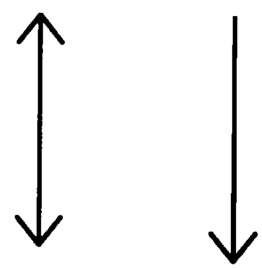
Non dimensional X-velocity

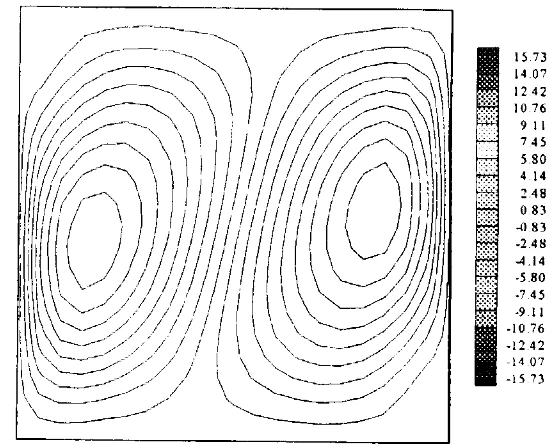
RESIDUAL-G (1.0 μg)+G-JITTER (3Hz)
$\alpha_g = \alpha_j = 90$ (deg) -- Time = 600 (s) cont'd

DIRECT FORMULATION **TIME-AVERAGED FORMULATION**

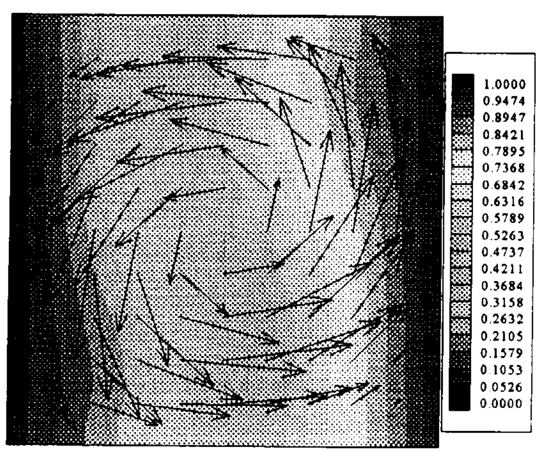


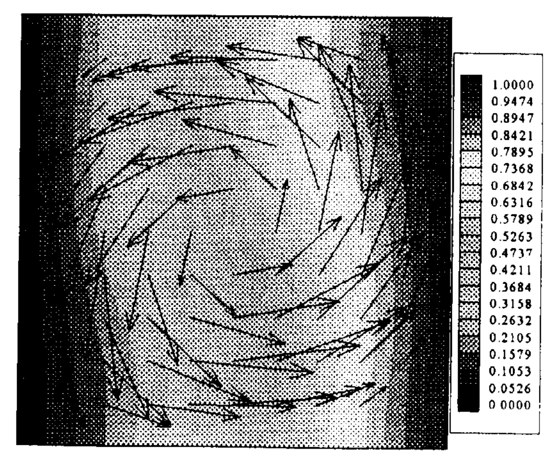
G-Jitter **Residual-g**





Non dimensional Y-velocity





$V_{max}/V_{\alpha} = 15.52$ Non Dimensional Temperature $V_{max}/V_{\alpha} = 15.37$

NUMERICAL RESULTS

Examination of the above graphs show that:

1) The results in terms of convective flows and temperature distortions are practically coincident for both a single frequency vibration and for the simultaneous application of a residual-g plus vibration)

2) Even during start-up (i.e. during unsteady phases) the time-average and the “direct” formulations give the same results

3) The comparison between the two codes becomes better and better if the ratios:

$$\frac{\text{frequency of the acceleraton}}{\text{thermal characteristic frequency}} = \frac{\omega}{\alpha / L^2} >> 1 \qquad \frac{\text{equivalent length scale}}{\text{amplitude of displacement}} = \frac{L / \beta_T \Delta T}{b} >> 1$$

4) For typical ISS MGE and for the selected study case the two ratios:

$$\frac{\omega L^2}{\alpha} > 10^4 \qquad \frac{L}{b \beta_T \Delta T} > 10^3$$

EVALUATION OF A LUMPED EQUIVALENT G-JITTER

A fundamental advantage of time-averaging the field equations is that the overall effect of many simultaneously acting vibrations can be easily numerically computed.

Numerical simulations have been carried out to extend the initial model for single frequency oscillation to the multifrequency g-jitter environment of the Space Station.

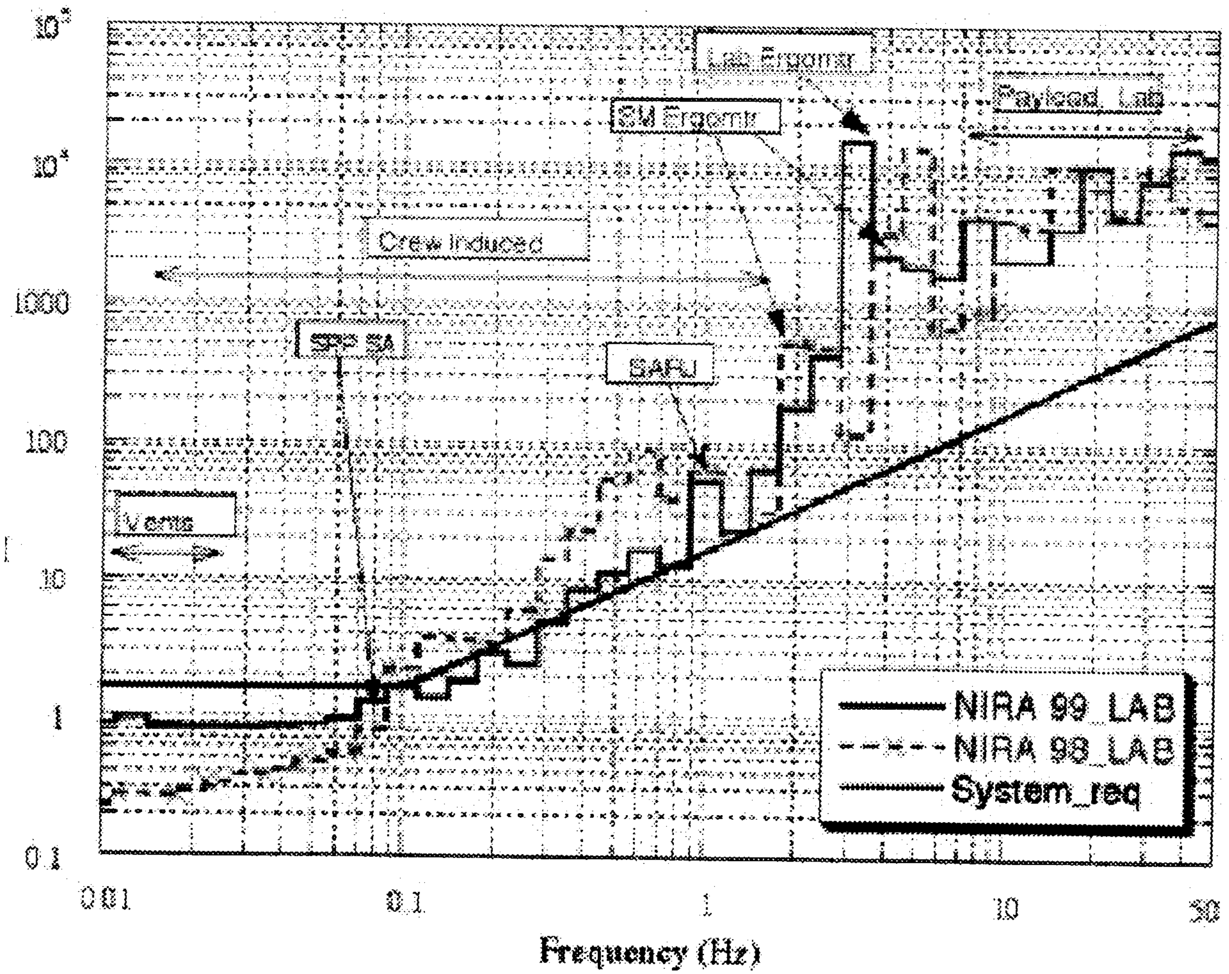
The numerical results show that the overall "time-averaged" disturbances of the thermo-fluid-dynamic field, in the presence of the typical microgravity environment of the ISS, can be simply evaluated assigning as input to the CFD code a single frequency g-jitter equivalent to an overall vibrational Rayleigh number $Ra_v = \Sigma Ra_{vi}$.

MULTI-FREQUENCY ISS MICROGRAVITY ENVIRONMENT

Acceleration

RMS

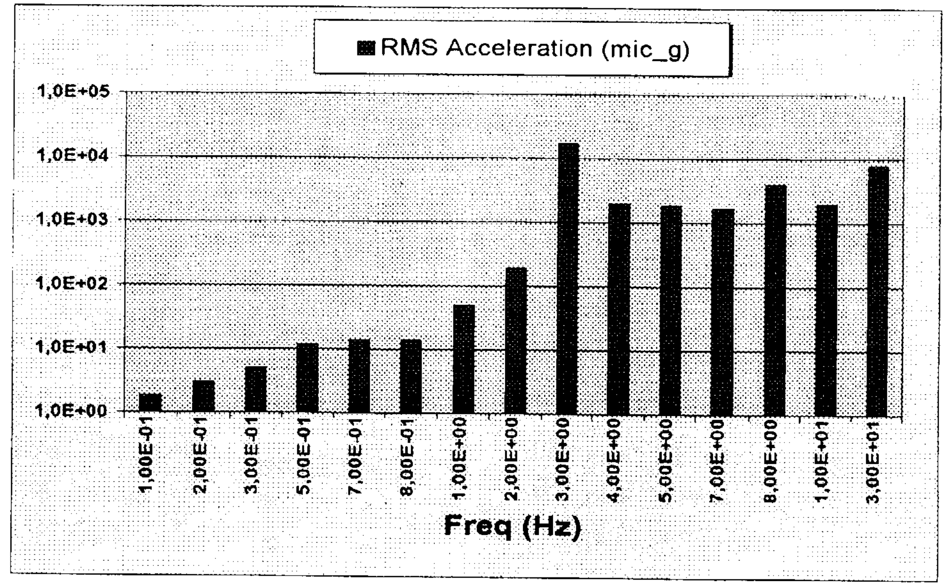
(μg)



DATA-BASE OF PHYSICAL, GEOMETRICAL PROPERTIES AND ACCELERATIONS (US-Lab)

Equivalent Acceleration:

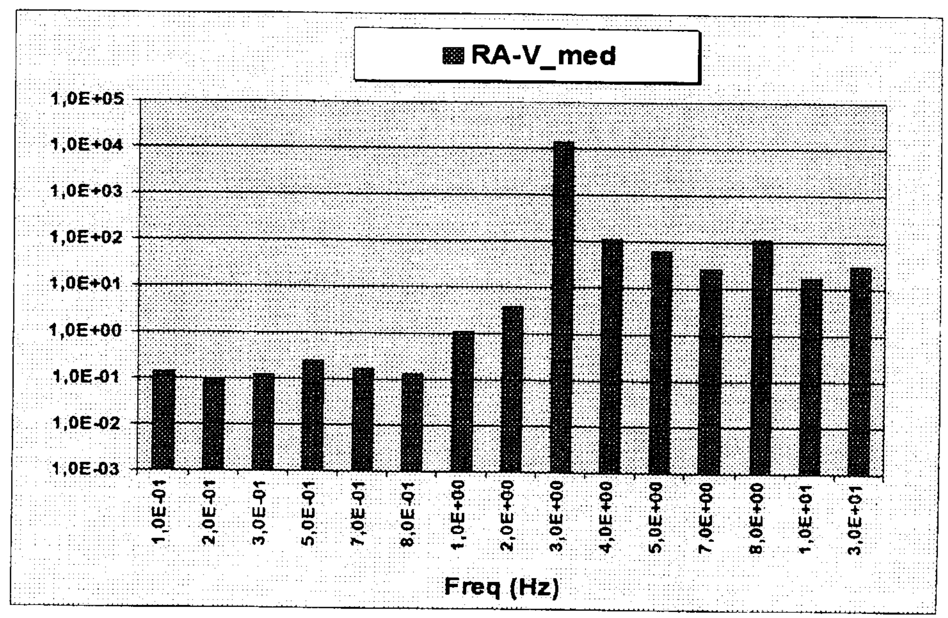
$$g^{j}_{eq} = \sqrt{\sum_{i=1}^{n\_freq} \left(g_i * \frac{f_j}{f_i} \right)^2}$$



Equivalent Vibrational Rayleigh number

$$Ra_v = \sum_i Ra_{vi} = 0.45 \frac{(b\beta_T \Delta TL)^2}{\nu\alpha}$$

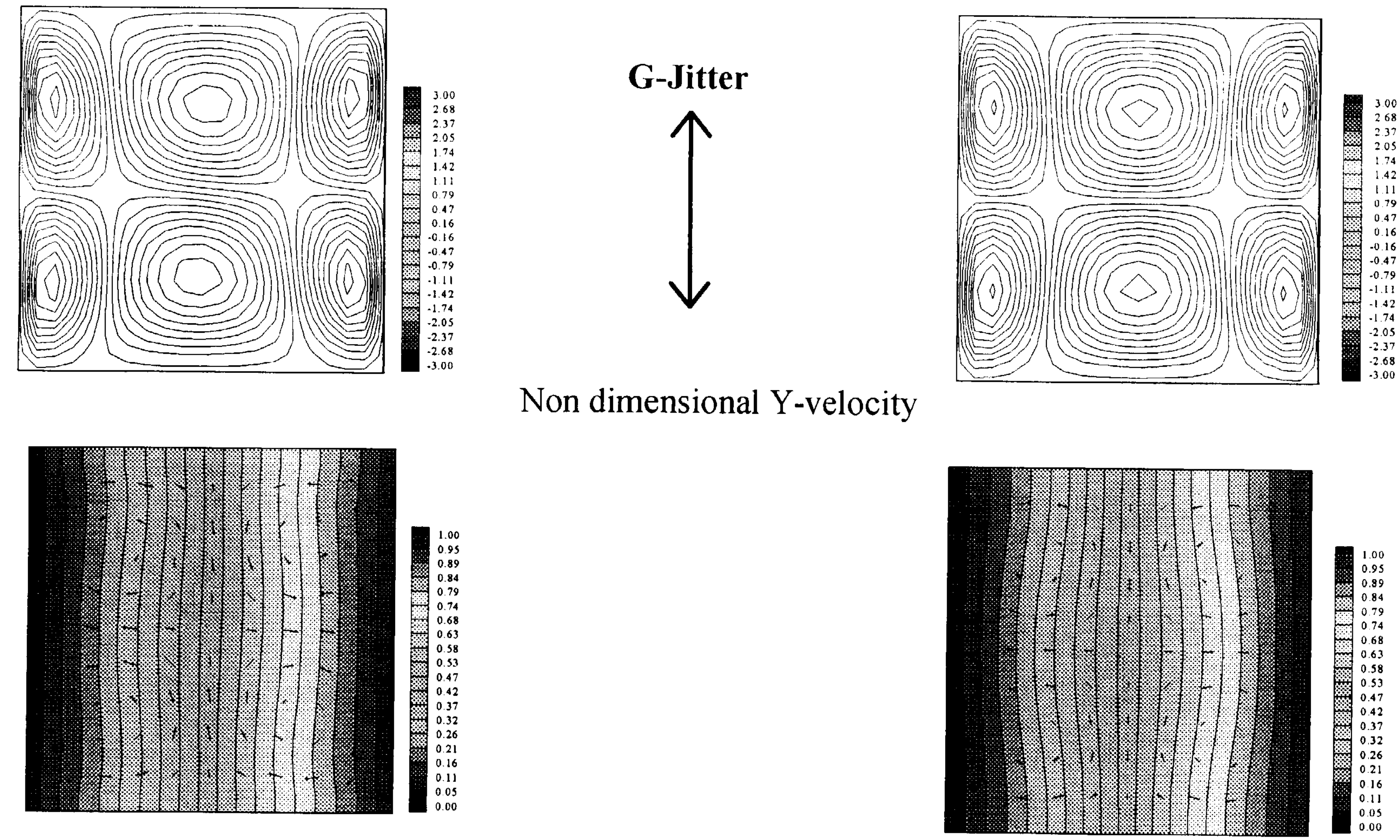
=14000



US-LAB Module (NIRA 99)

G_ Jitter [(15 frequencies) --- α_j=-90 (deg)] --- Time=600 (s)]

DIRECT FORMULATION **TIME-AVERAGED FORMULATION**



$V_{max}/V_{\alpha} = 3.15$ Non Dimensional Temperature $V_{max}/V_{\alpha} = 3.17$

EFFECT OF RESIDUAL-G AND G-JITTER AT DIFFERENT ISS LOCATIONS

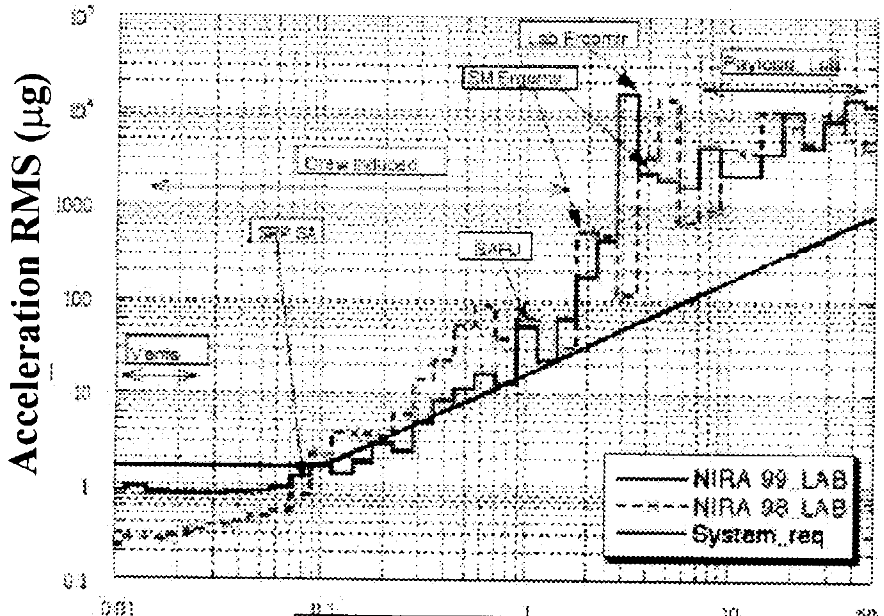
Numerical simulations have been carried out to evaluate the residual-g and g-jitter effects on the same experimental cell located inside different modules of the ISS.

The accelerations given as input to the CFD code correspond to the recent NIRA 99 predictions for the US Lab and for the ESA-COF.

Due to the large extension of the ISS, the results show that the Space Station can be seen as an ensemble of MG platforms, due to the substantial differences (in the convective disturbances) encountered by the experimental facility when located inside different modules of the ISS.

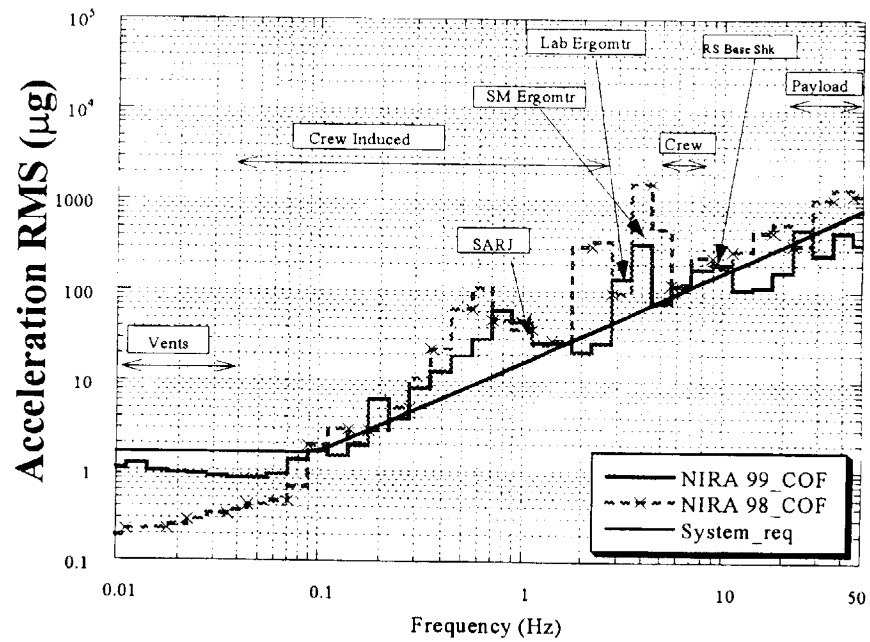
MICROGRAVITY ENVIRONMENT

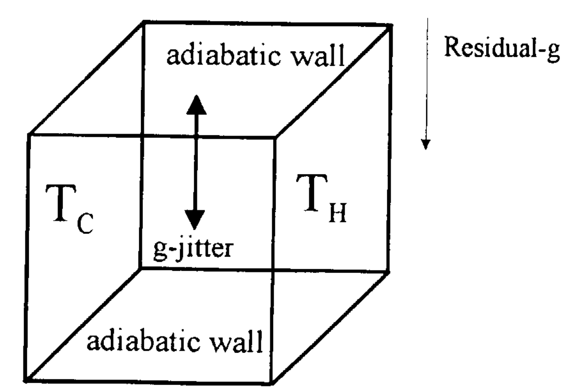
US LAB MODULE NIRA 99



Oil 0.65 cs	
β_T= 1,3000E-03	(1/K)
λ= 1,2000E-01	(W/m/K)
µ= 5,7200E-04	(Kg/m/s)
Cp= 2,0000E+03	(Joule/Kg/K)
ρ_0= 8,8000E+02	(Kg/m^3)
Residual_g= 1,6000E-05	(m/s^2)
L= 6,0000E-02	(m)
ΔT= 5,0000E+01	(K)
α= 6,8182E-08	(m^2/s)
ν= 6,5000E-07	(m^2/s)
t_{rif}= 5,2800E+04	(s)
Pr= 9,5333E+00	
Rag= 5,0688E+03	

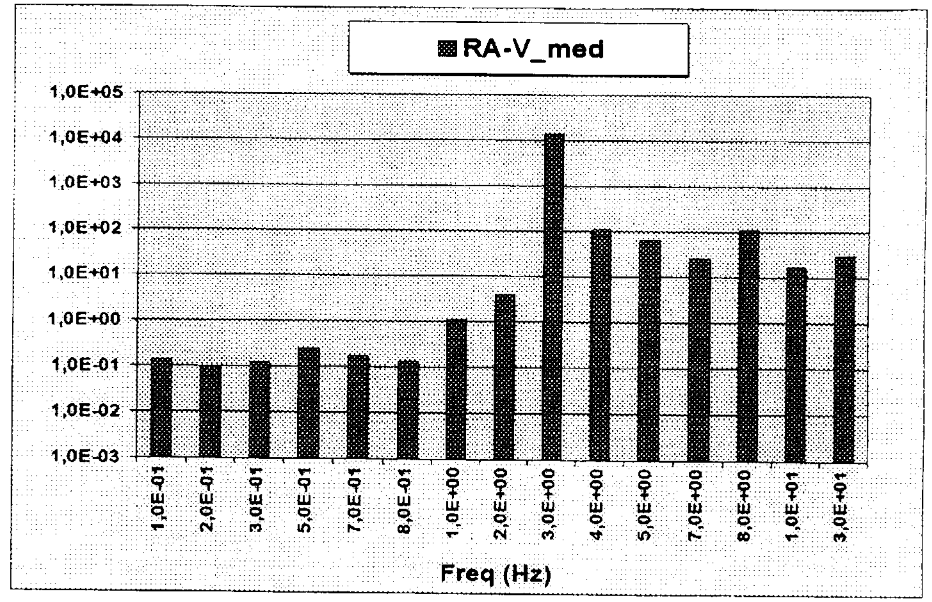
ESA COF MODULE NIRA 99





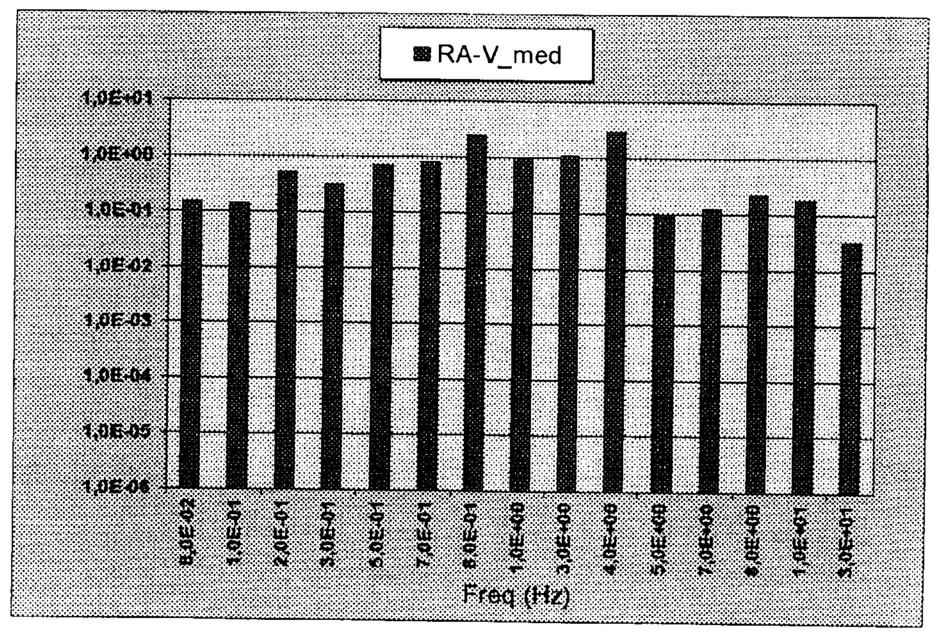
U.S. Lab

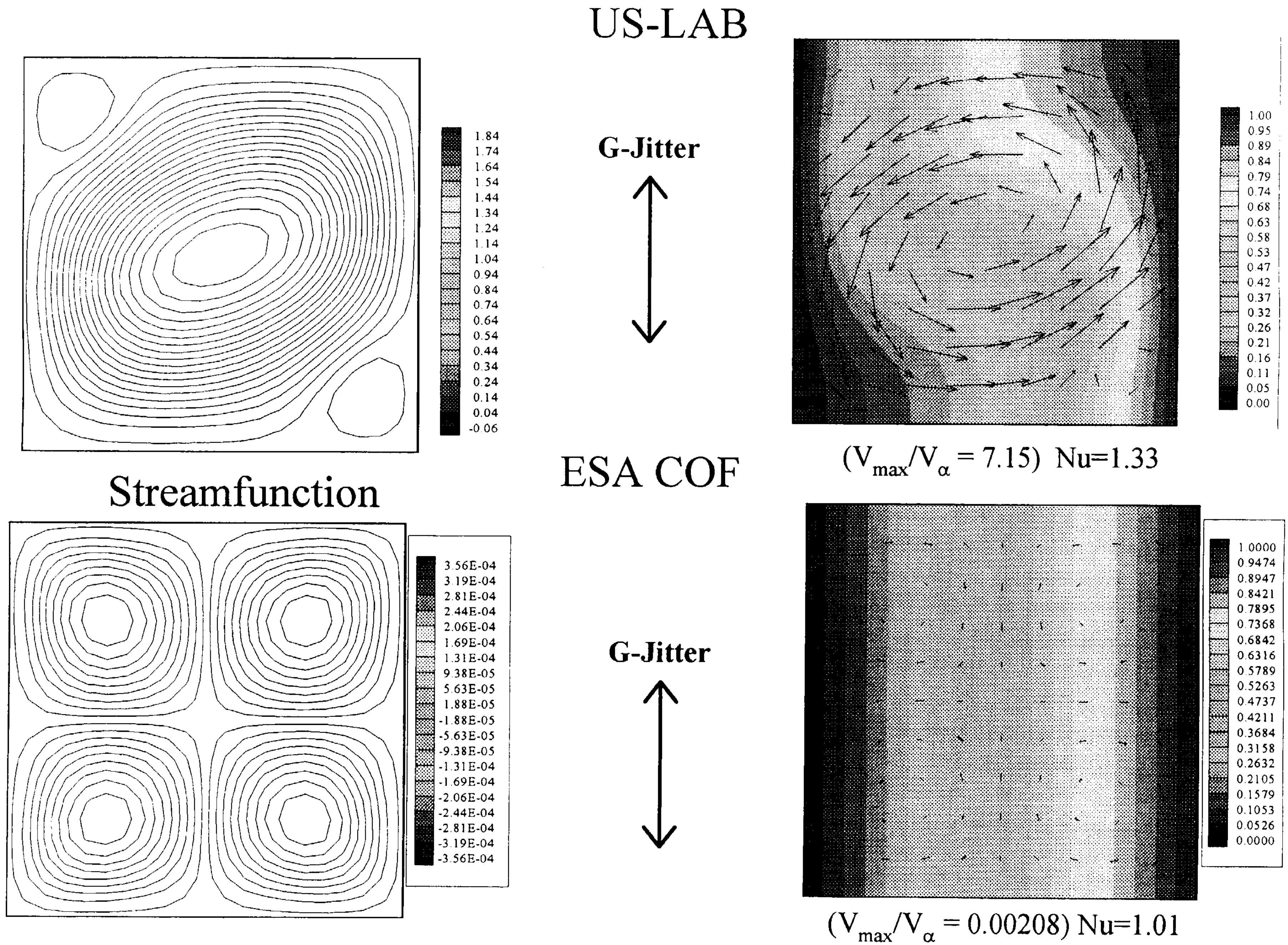
$Ra_v = \Sigma Ra_{vi} = 14000$

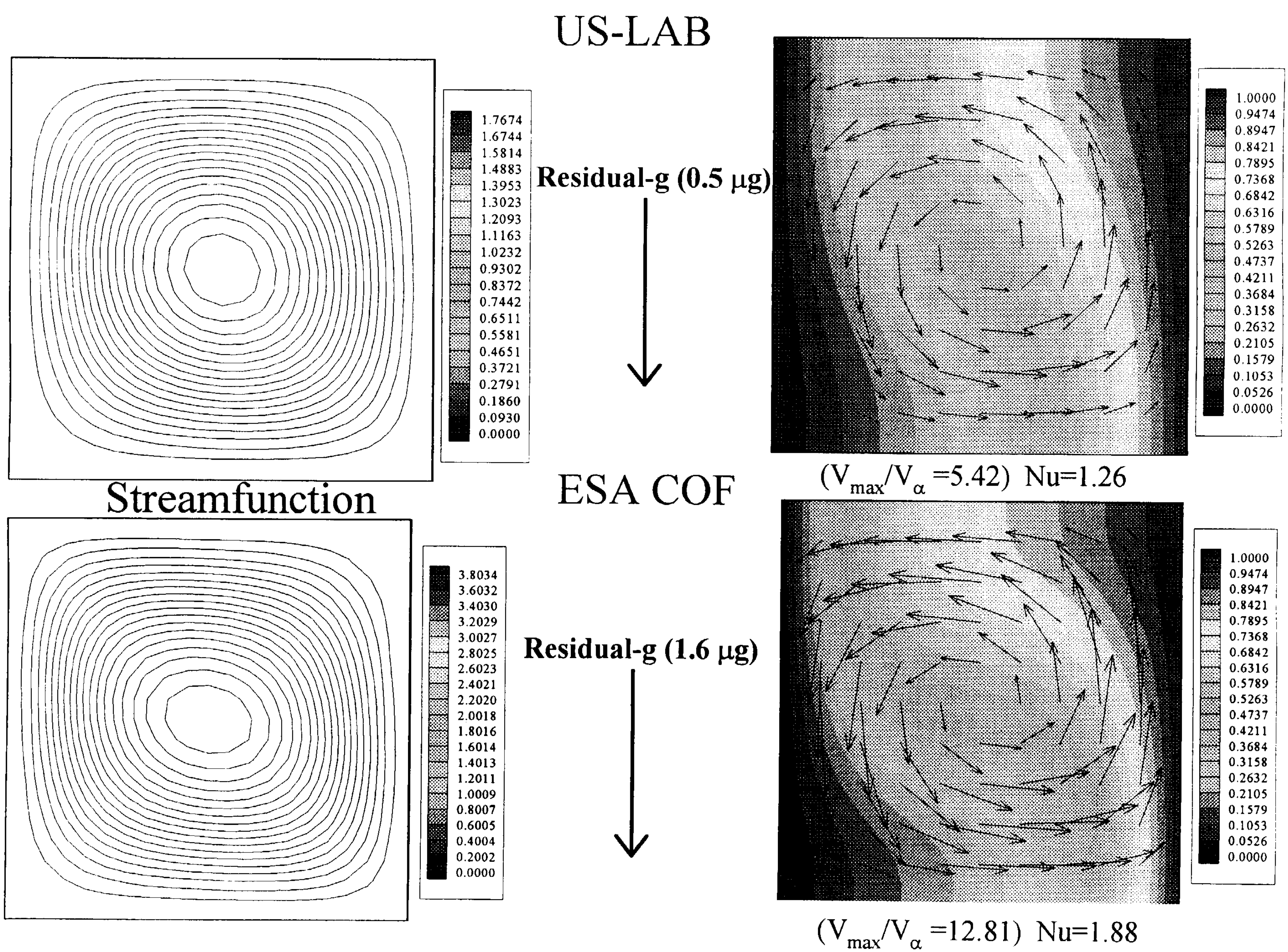


ESA - COF

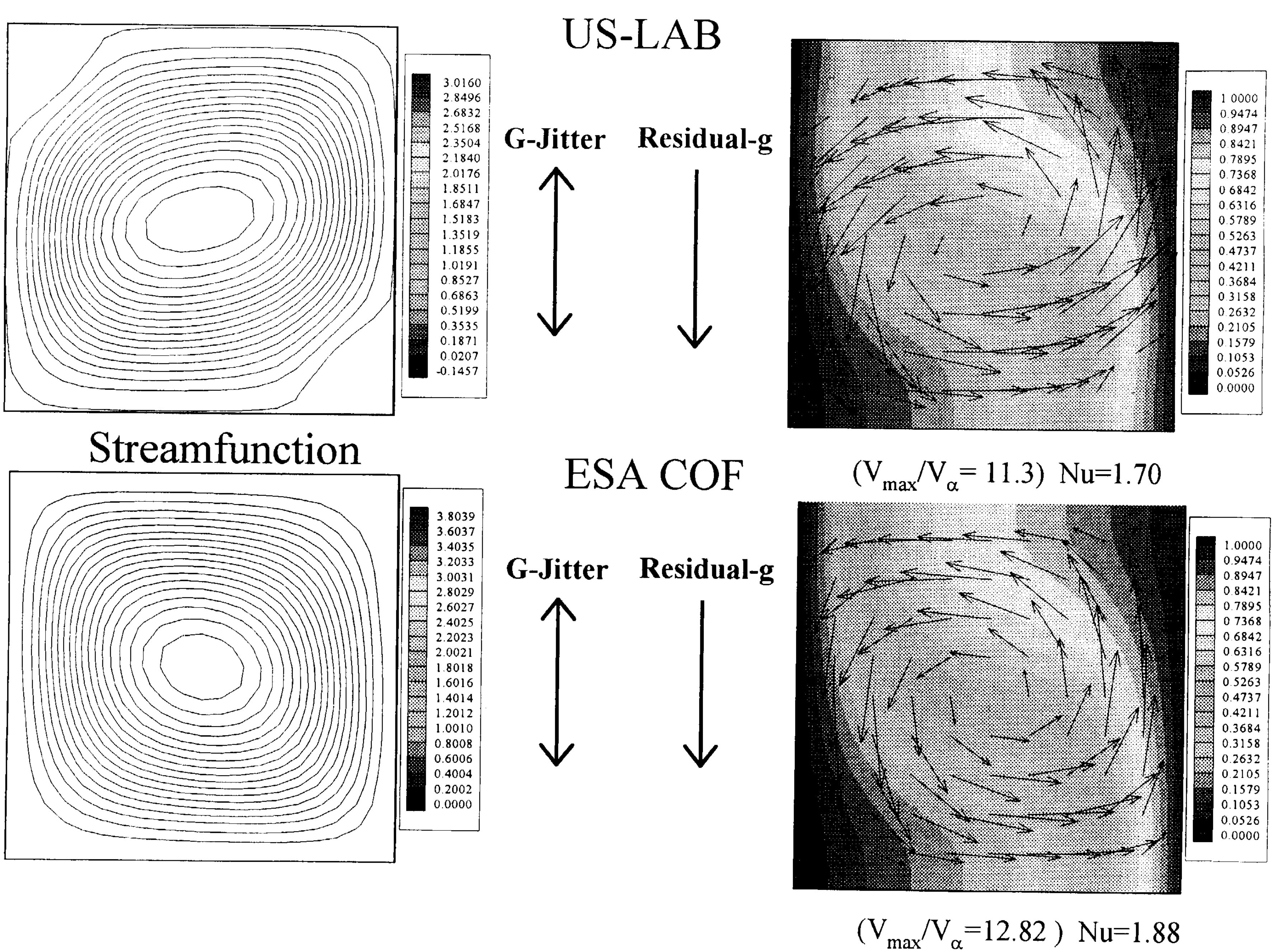
$Ra_v = \Sigma Ra_{vi} = 10.5$




US-LAB
G-Jitter
1.84
1.74
1.64
1.54
1.44
1.34
1.24
1.14
1.04
0.94
0.84
0.74
0.64
0.54
0.44
0.34
0.24
0.14
0.04
-0.06
1.00
0.95
0.89
0.84
0.79
0.74
0.68
0.63
0.58
0.53
0.47
0.42
0.37
0.32
0.26
0.21
0.16
0.11
0.05
0.00
(V_{max}/V_{α} = 7.15) Nu=1.33
ESA COF
Streamfunction
G-Jitter
3.56E-04
3.19E-04
2.81E-04
2.44E-04
2.06E-04
1.69E-04
1.31E-04
9.38E-05
5.63E-05
1.88E-05
-1.88E-05
-5.63E-05
-9.38E-05
-1.31E-04
-1.69E-04
-2.06E-04
-2.44E-04
-2.81E-04
-3.19E-04
-3.56E-04
1.0000
0.9474
0.8947
0.8421
0.7895
0.7368
0.6842
0.6316
0.5789
0.5263
0.4737
0.4211
0.3684
0.3158
0.2632
0.2105
0.1579
0.1053
0.0526
0.0000
(V_{max}/V_{α} = 0.00208) Nu=1.01



US-LAB
Residual-g (0.5 μg)
Streamfunction
1.7674
1.6744
1.5814
1.4883
1.3953
1.3023
1.2093
1.1163
1.0232
0.9302
0.8372
0.7442
0.6511
0.5581
0.4651
0.3721
0.2791
0.1860
0.0930
0.0000
1.0000
0.9474
0.8947
0.8421
0.7895
0.7368
0.6842
0.6316
0.5789
0.5263
0.4737
0.4211
0.3684
0.3158
0.2632
0.2105
0.1579
0.1053
0.0526
0.0000
(V_{max}/V_{α} =5.42) Nu=1.26
ESA COF
Residual-g (1.6 μg)
3.8034
3.6032
3.4030
3.2029
3.0027
2.8025
2.6023
2.4021
2.2020
2.0018
1.8016
1.6014
1.4013
1.2011
1.0009
0.8007
0.6005
0.4004
0.2002
0.0000
1.0000
0.9474
0.8947
0.8421
0.7895
0.7368
0.6842
0.6316
0.5789
0.5263
0.4737
0.4211
0.3684
0.3158
0.2632
0.2105
0.1579
0.1053
0.0526
0.0000
(V_{max}/V_{α} =12.81) Nu=1.88

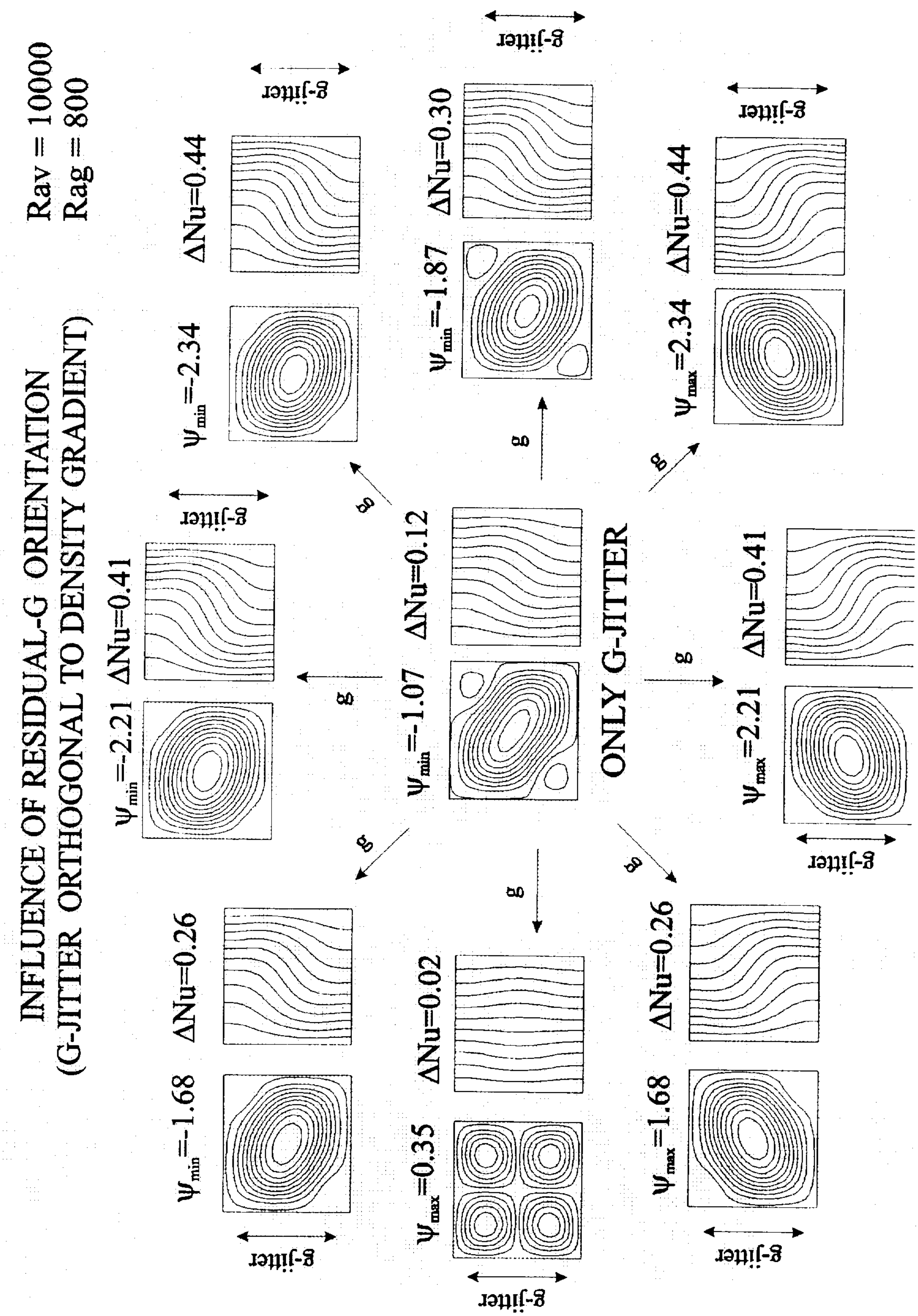

US-LAB
G-Jitter
Residual-g
3.0160
2.8496
2.6832
2.5168
2.3504
2.1840
2.0176
1.8511
1.6847
1.5183
1.3519
1.1855
1.0191
0.8527
0.6863
0.5199
0.3535
0.1871
0.0207
-0.1457
1.0000
0.9474
0.8947
0.8421
0.7895
0.7368
0.6842
0.6316
0.5789
0.5263
0.4737
0.4211
0.3684
0.3158
0.2632
0.2105
0.1579
0.1053
0.0526
0.0000
Streamfunction
ESA COF
(V_{max}/V_{α} = 11.3) Nu=1.70
G-Jitter
Residual-g
3.8039
3.6037
3.4035
3.2033
3.0031
2.8029
2.6027
2.4025
2.2023
2.0021
1.8018
1.6016
1.4014
1.2012
1.0010
0.8008
0.6006
0.4004
0.2002
0.0000
1.0000
0.9474
0.8947
0.8421
0.7895
0.7368
0.6842
0.6316
0.5789
0.5263
0.4737
0.4211
0.3684
0.3158
0.2632
0.2105
0.1579
0.1053
0.0526
0.0000
(V_{max}/V_{α}=12.82) Nu=1.88

INFLUENCE OF CELL ORIENTATION

Numerical simulations have been carried out to evaluate the influence of the cell orientation with respect to the residual-g and g-jitter vectors.

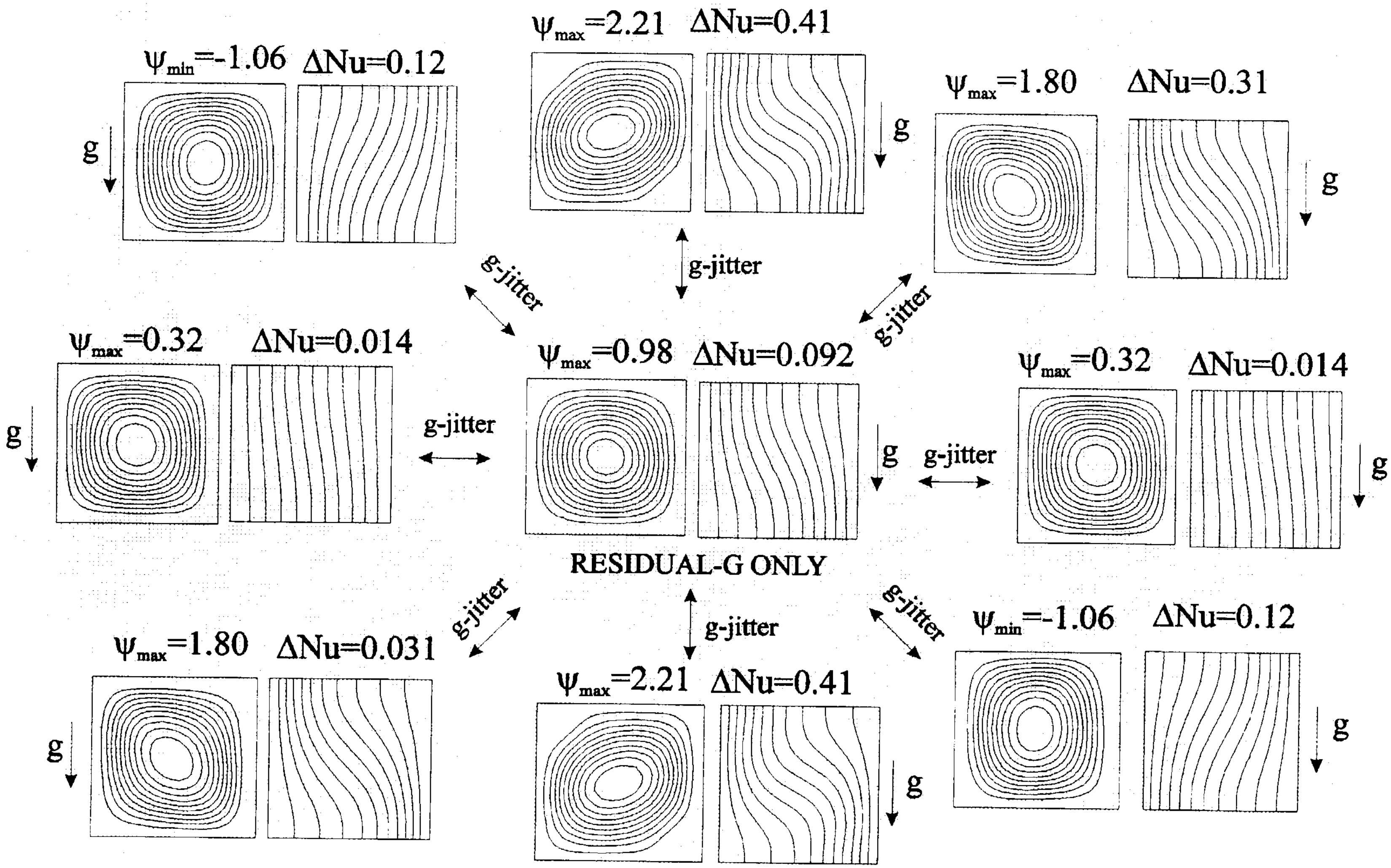
Different orientations of the residual-g and g-jitter (stabilizing or destabilizing) have been considered.

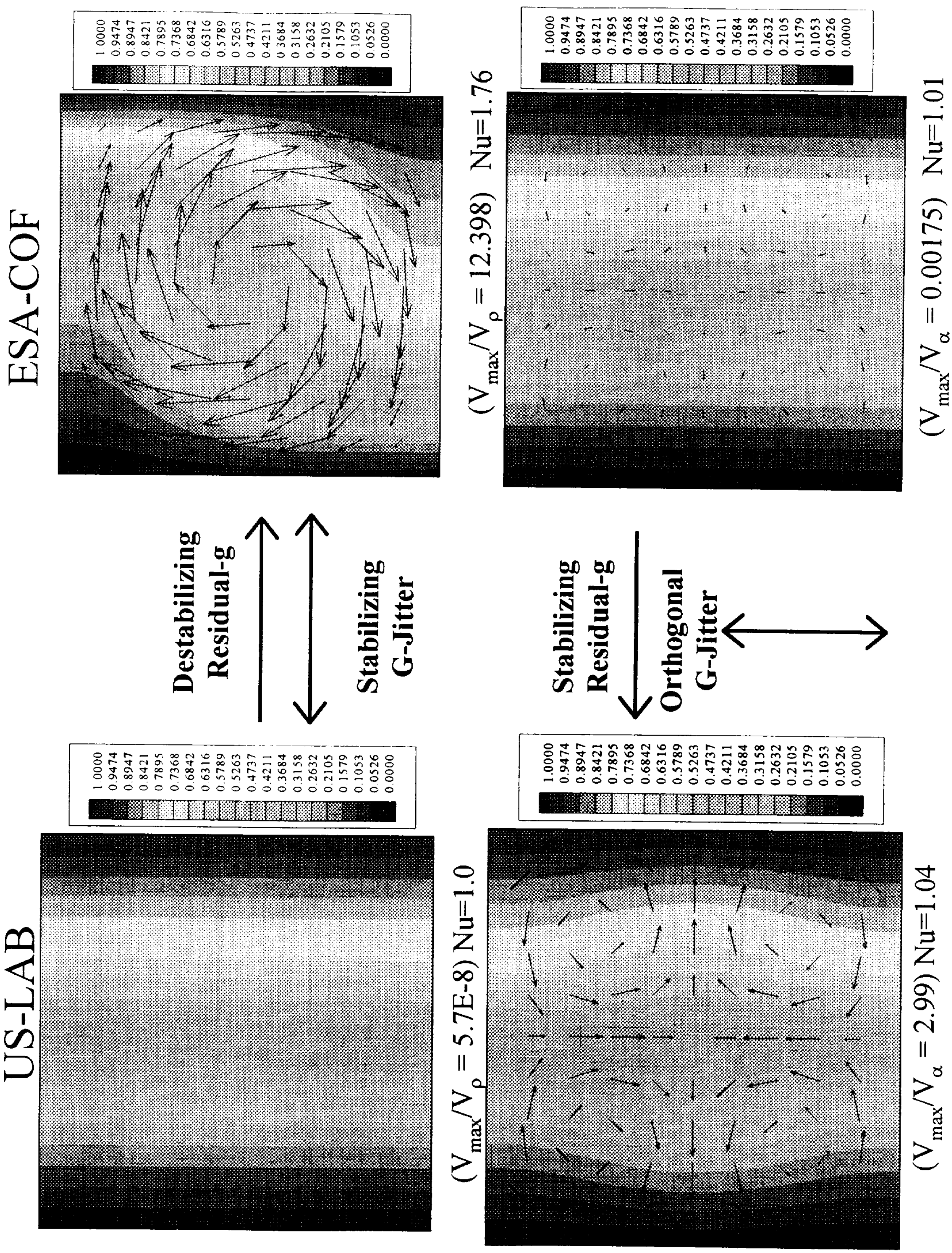
The results show that Isolation Mounts, that strongly reduce "high" frequency g-jitter, are probably justified in ISS locations (like the US Lab) where very low values of the residual-g prevail. In other locations (like the ESA-COF) the presence of a large residual-g and of an orientation capability could in some cases provide a controllable convective transport of heat and of species to optimize microgravity processes .


INFLUENCE OF RESIDUAL-G ORIENTATION
(G-JITTER ORTHOGONAL TO DENSITY GRADIENT)
Rav = 10000
Rag = 800
ONLY G-JITTER
ψ_{min}=-1.07
ΔNu=0.12
ψ_{min}=-2.34
ΔNu=0.44
ψ_{min}=-1.87
ΔNu=0.30
ψ_{max}=2.34
ΔNu=0.44
ψ_{min}=-2.21
ΔNu=0.41
ψ_{max}=2.21
ΔNu=0.41
ψ_{min}=-1.68
ΔNu=0.26
ψ_{max}=0.35
ΔNu=0.02
ψ_{max}=1.68
ΔNu=0.26
g
g-jitter

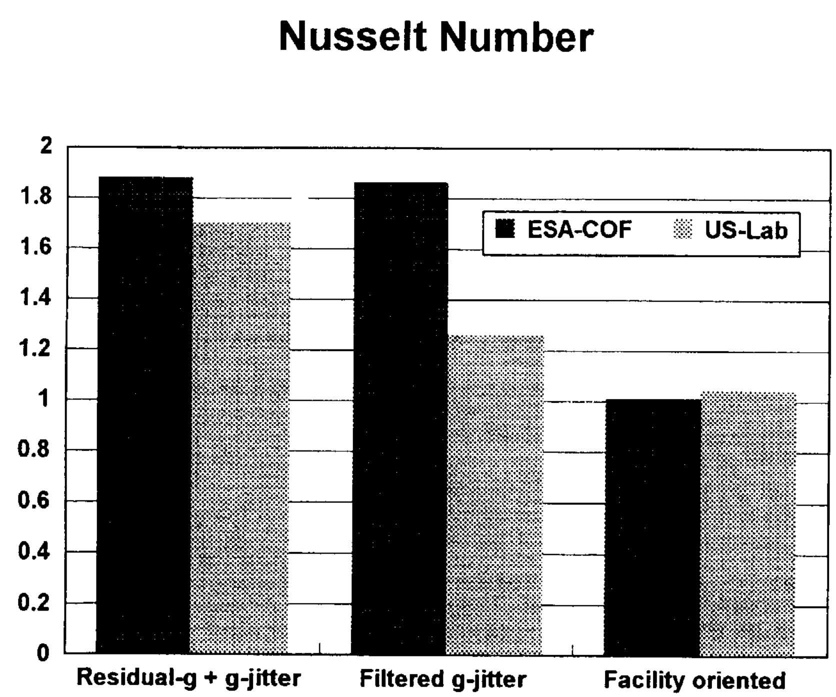
INFLUENCE OF G-JITTER ORIENTATION
(RESIDUAL-G ORTHOGONAL TO DENSITY GRADIENT)

Rav = 10000
Rag = 800




US-LAB
ESA-COF
1.0000
0.9474
0.8947
0.8421
0.7895
0.7368
0.6842
0.6316
0.5789
0.5263
0.4737
0.4211
0.3684
0.3158
0.2632
0.2105
0.1579
0.1053
0.0526
0.0000
Destabilizing
Residual-g
Stabilizing
G-Jitter
Stabilizing
Residual-g
Orthogonal
G-Jitter
(V_{max}/V_ρ = 5.7E-8) Nu=1.0
($V_{max}/V_\rho = 12.398$) Nu=1.76
($V_{max}/V_\alpha = 2.99$) Nu=1.04
($V_{max}/V_\alpha = 0.00175$) Nu=1.01

COMPUTED NUSSELT NUMBER

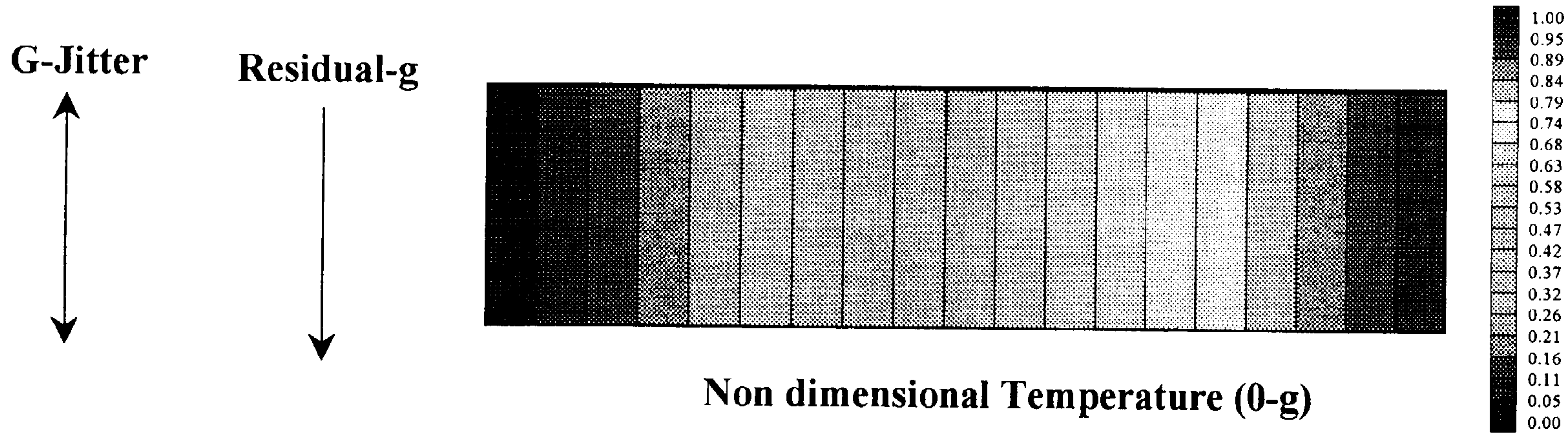


(ARIS)

	α_G	α_J	Nusselt Number (US Lab) Residual-g = 0.5 μg G-Jitter: NIRA 99 15 freq.	Nusselt Number (ESA COF) Residual-g = 1.6 μg G-Jitter: NIRA 99 15 freq.
Residual-G	-90		1.26	1.88
G-Jitter		-90	1.33	1.00
Residual-G+Jitter	-90	-90	1.70	1.88
Residual-G+Jitter	180	-90	1.04	1.00
Residual-G	0		1.00	1.76
Residual-G+Jitter	0	-90	1.61	1.76
G+Jitter		180	1.00	1.00
Residual-G+Jitter	-90	180	1.03	1.88
Residual-G+Jitter	180	180	1.00	1.00
Residual-G+Jitter	0	180	1.00	1.76

It seems that orientation is more efficient than Isolation Mount to minimize convective disturbances. However, when residual-g is negligible, orientation works only if the dominant g-jitter direction is known

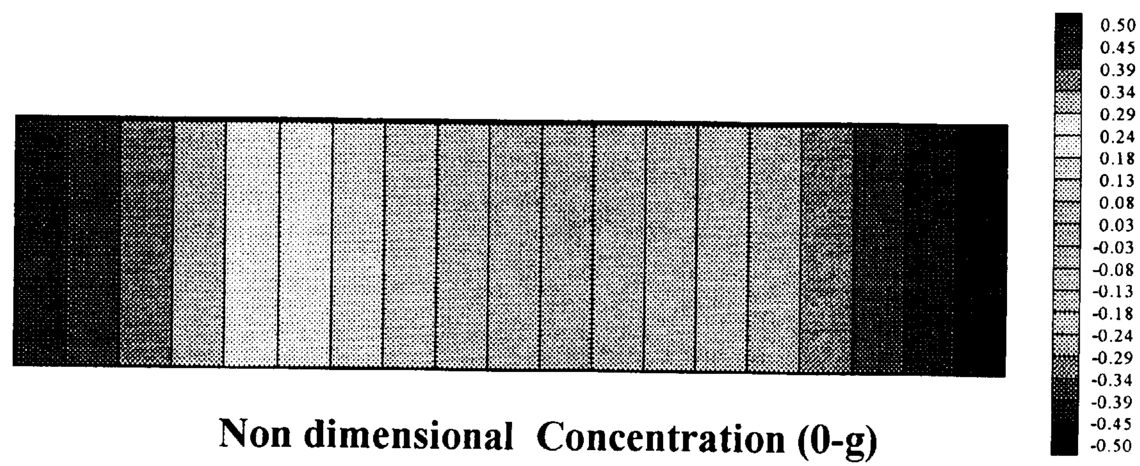
APPLICATION TO THE THERMODIFFUSION MEASUREMENT IN A METAL ALLOY



Non dimensional Temperature (0-g)

$$\frac{\Delta C}{C_0} = -S_t * \Delta T$$

S_t: Soret coefficient



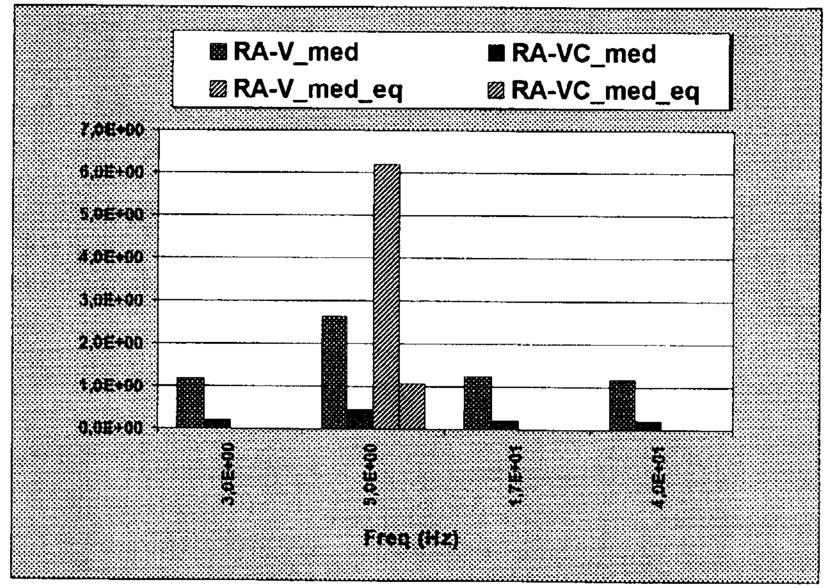
Non dimensional Concentration (0-g)

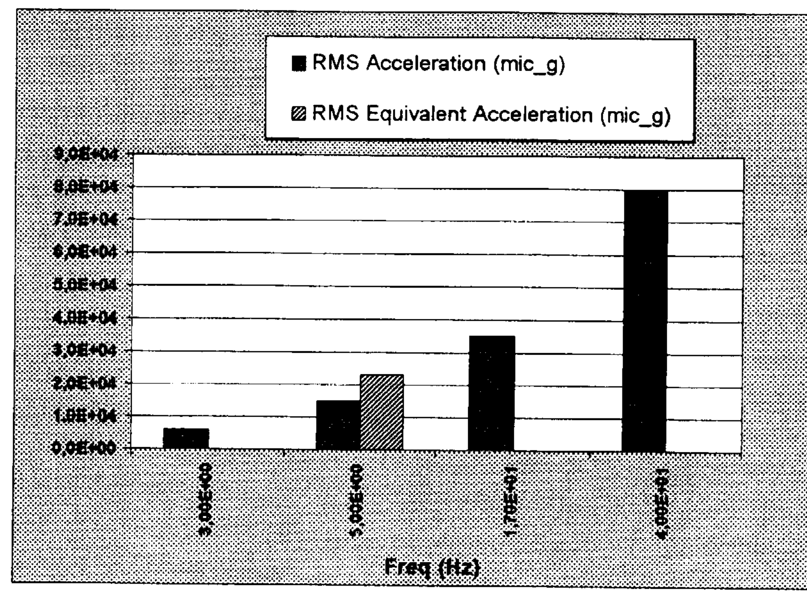
THERMODIFFUSION IN A METAL ALLOY. DATA-BASE OF PHYSICAL, GEOMETRICAL PROPERTIES AND ACCELERATIONS

Metal Alloy	
β_T= 1,20E-04	*(1/K)*
β_C= 1,00E+00	*(Kg/m^3)*
α= 1,00E-05	*(m^2/s)*
ν= 1,00E-07	*(m^2/s)*
H= 1,00E-02	*(m)*
L= 0.04	*(m)*
ΔT= 4,00E+02	*(K)*
S= 1,00E-03	*(1/K)*
C_0= 5,00E-02	*mass-fraction*
Di,j= 1,00E-09	*(m^2/s)*
Residual_g= 1,00E-05	*(m/s^2)*
ΔC= 2,00E-02	*mass-fraction*
trif= 1,00E+01	*(s)*
Pr= 1,00E-02	
Sc= 1,00E+02	
Rag= 4,80E-01	
Rag_C= 2,00E-01	

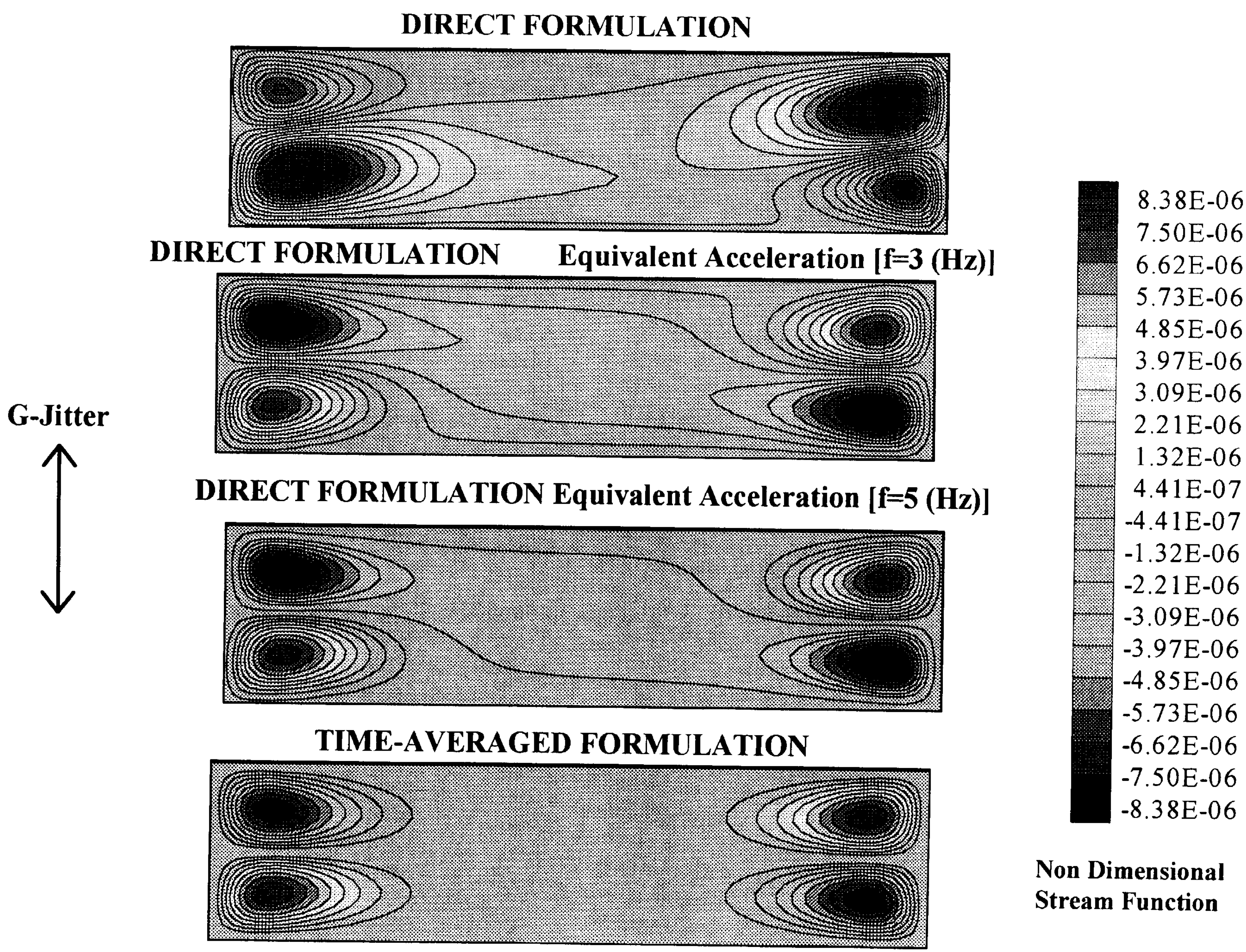
Equivalent Acceleration:

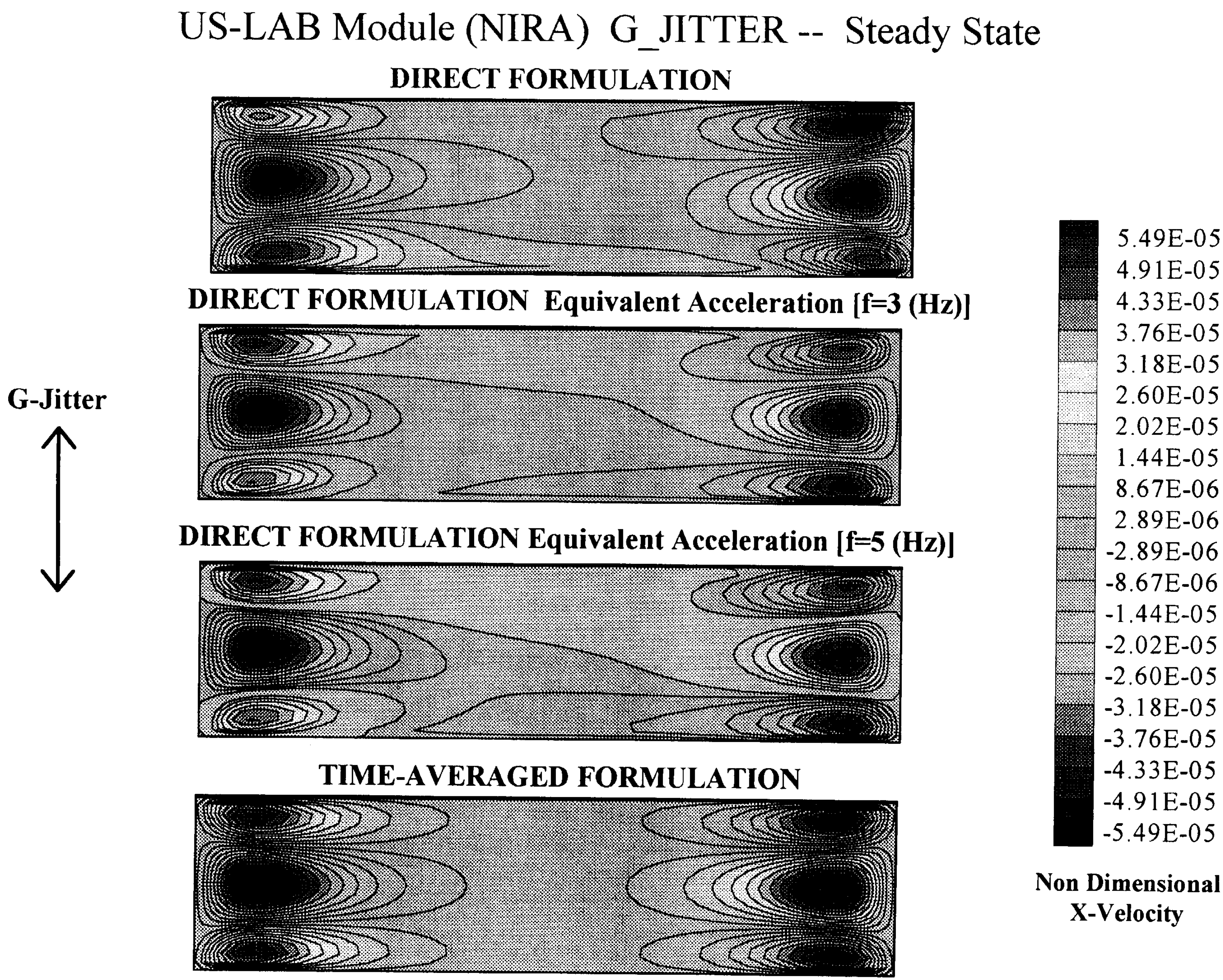
$$g_{eq}^{j} = \sqrt{\sum_{i=1}^{n\_freq} \left(g_i * \frac{f_j}{f_i} \right)^2}$$



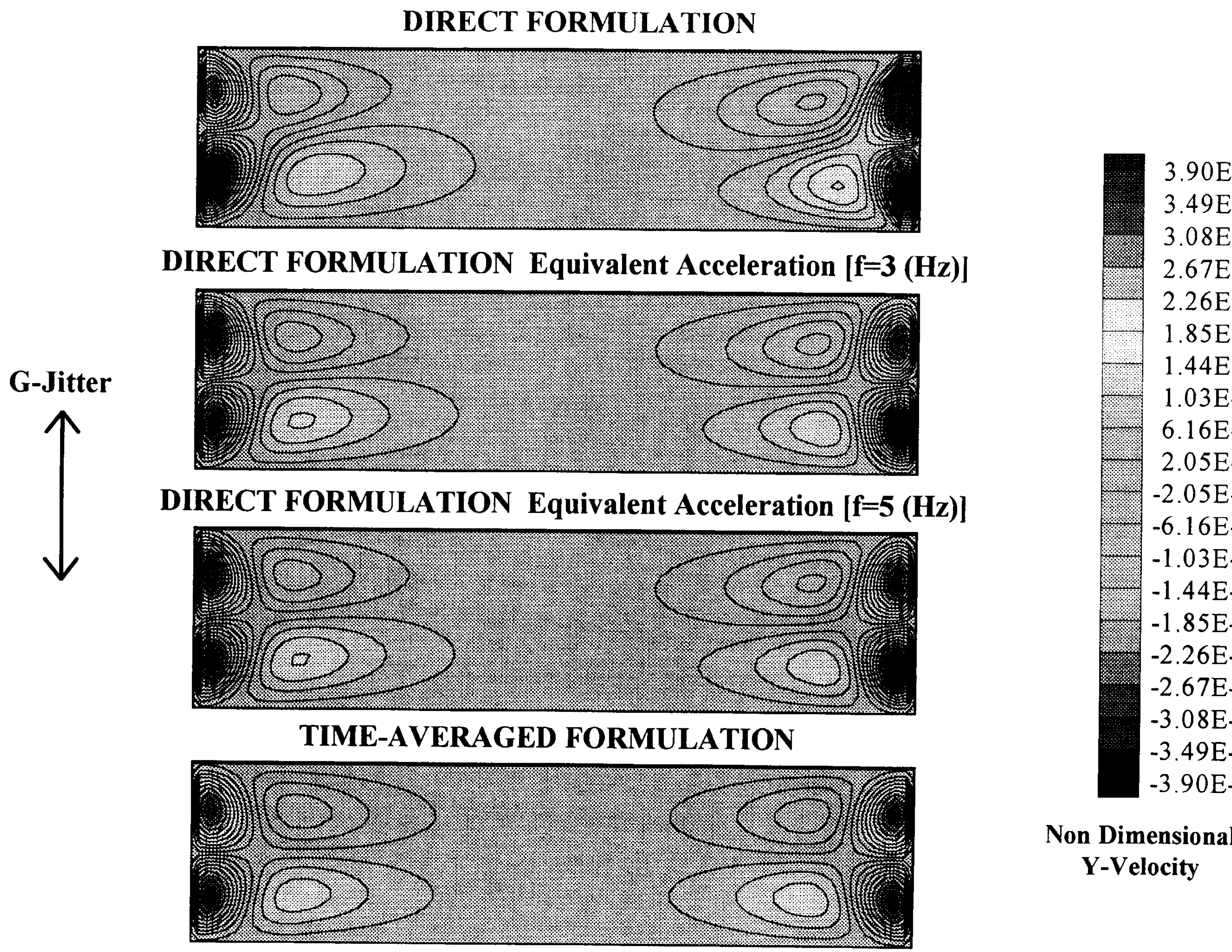


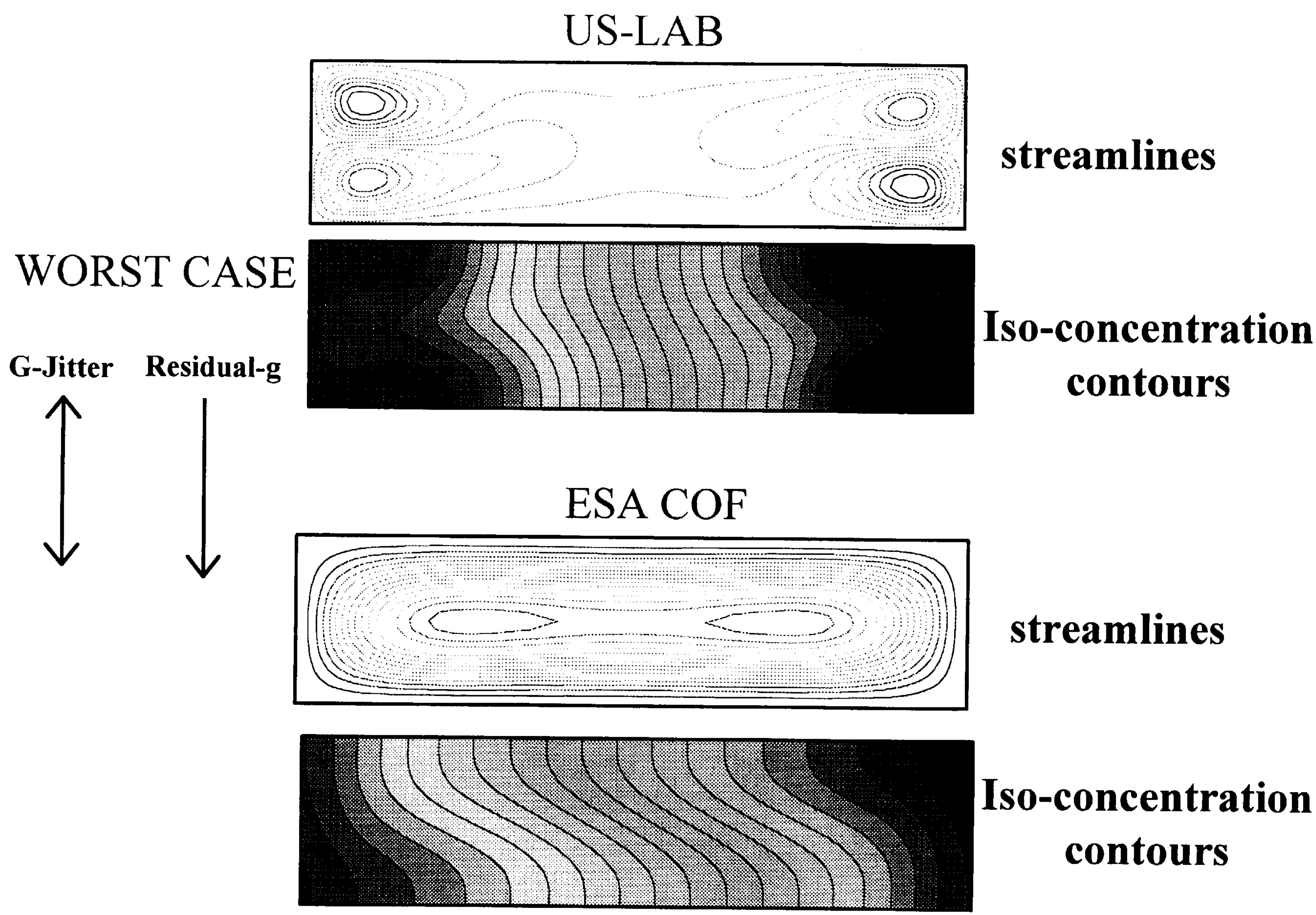
US-LAB Module (NIRA) G_JITTER -- Steady State




US-LAB Module (NIRA) G_JITTER -- Steady State
DIRECT FORMULATION
DIRECT FORMULATION Equivalent Acceleration [f=3 (Hz)]
DIRECT FORMULATION Equivalent Acceleration [f=5 (Hz)]
TIME-AVERAGED FORMULATION
G-Jitter
5.49E-05
4.91E-05
4.33E-05
3.76E-05
3.18E-05
2.60E-05
2.02E-05
1.44E-05
8.67E-06
2.89E-06
-2.89E-06
-8.67E-06
-1.44E-05
-2.02E-05
-2.60E-05
-3.18E-05
-3.76E-05
-4.33E-05
-4.91E-05
-5.49E-05
Non Dimensional
X-Velocity

US-LAB Module (NIRA) G_JITTER -- Steady State




US-LAB
streamlines
Iso-concentration contours
WORST CASE
G-Jitter
Residual-g
ESA COF
streamlines
Iso-concentration contours

CONCLUSIONS (1)

A numerical tool has been prepared to quickly predict the overall g-jitter disturbances for typical microgravity environment of ISS

The code has been employed to simulate a simple reference study case and applied to study a problem of thermodiffusion in a metal alloy

In presence of both residual-g and g-jitter the cell orientation can be very beneficial to reduce convective disturbances

The best orientation depends on the residual-g amplitude and direction and on the predominant g-jitter amplitude and direction

CONCLUSIONS (2)

In the US Lab (large g-jitter and small residual-g) the cell should be oriented with the density gradient axis parallel to the axis of the main source of vibration

In the COF (rather large residual-g and small g-jitter) the cell should be oriented with the density gradient axis parallel to the residual-g

To experimentally check the above conclusions a number of Fluid Physics experiments will be accomodated on an orientable support on ISS (UF#3 mission)

53/62 20010019720 512569 17P

MGMG #19

Paper Number: 8

Drag induced acceleration of the Shuttle measured with a fluid cell

Charles A. Ward
University of Toronto
Toronto, Ontario, Canada

When the orbiting Space Shuttle has undergone a roll of 180° and a pitch 90°, it experiences an acceleration due gravitational attraction that is directed toward the center of the earth, and an acceleration, or drag in the direction opposite to the velocity vector that is perpendicular to the gravitational acceleration. Measurements were made on STS–87 with a fluid cell that indicates the drag-induced acceleration (mean ± SDV) is $8 \pm 3 \mathrm{X} 10^{-4}\ g_0$.[1] This value is in agreement with the SAMS (Space Acceleration Measurement System) measurement, but in disagreement with the OARE (Orbital Acceleration Research Experiment) value.

The value inferred from the fluid cell is obtained by recording the configuration adopted by a two-phase fluid held in glass cylinder when present on the orbiting Space Shuttle. The recorded configuration is then compared with that predicted for different gravitational intensities. The predictions are based on the assumption of thermodynamic equilibrium. The value inferred from the fluid cell is larger than expected. Since it is based on the configuration that the fluid actually adopts when subjected to g-jitter, the result may be a g-jitter effect, or the drag-induced acceleration may in fact be larger than expected. To distinguish these possibilities, a series of ground-based studies have been performed with rotating fluids. The objective of these studies was to duplicate the conditions (temperature and pressure) that the two-phase fluid experienced in orbit. With the rotating fluids the conditions can be maintained essentially constant until the system comes to equilibrium. Under this circumstance, the assumption of thermodynamic equilibrium should be valid.

1. C. A. Ward, P. Rahimi, M. R. Sasges, D. Stanga, "Contact angle hysteresis in the residual gravitational field of the Space Shuttle", J. Chem. Phys. 112, 7195 (2000).

When the conditions (temperature and pressure) to which the fluid is subjected, but produced in the different circumstances (i.e. in rotation on earth and in orbit) are the same, the fluid configuration has been found to be the same. Although the drag-induced acceleration is larger than expected, it is calculated from the equations of motion to have a negligible effect on the Shuttle orbit. Thus, at this time it appears the drag-induced acceleration is larger than measured by OARE, but in agreement with SAMS.

Drag Induced Acceleration of the Shuttle Measured with a Fluid Cell

By

Charles A. Ward

Department of Mechanical and Industrial Engineering

University of Toronto,

Toronto, Canada M5S 3G8

Supported by the Canadian Space Agency

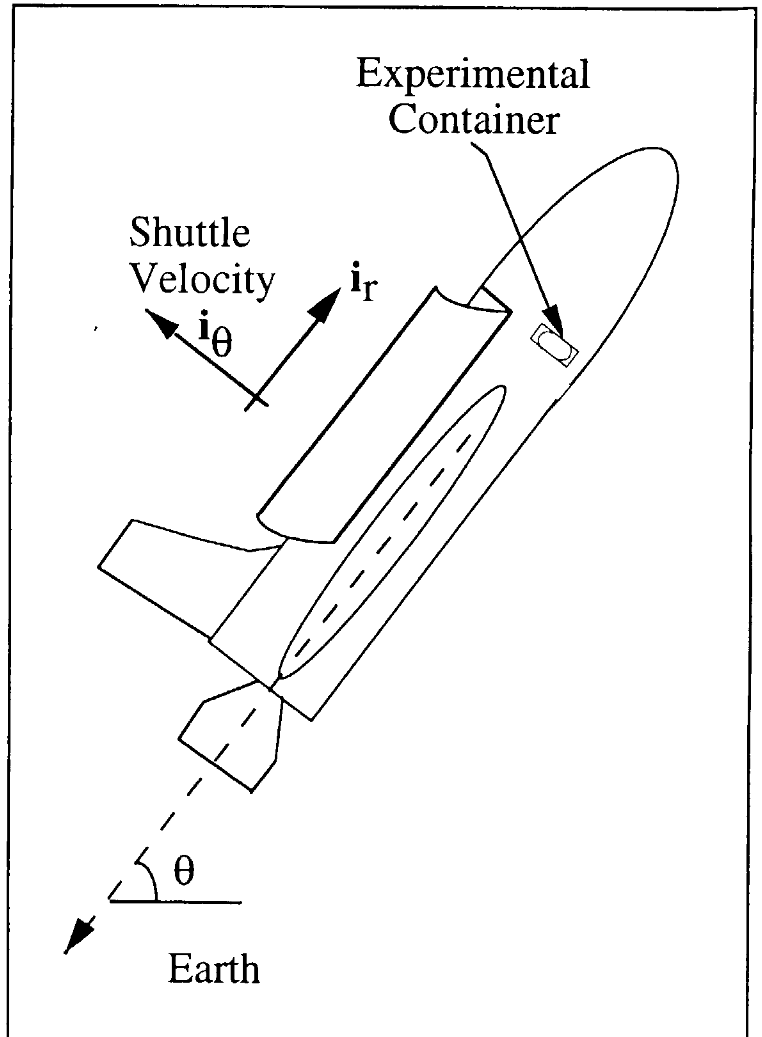
Drag-Induced Acceleration of the Shuttle

Measured with a fluid cell:

$$a_d \mathbf{i}_\theta = (8 \pm 3) \times 10^{-4} g_0 \mathbf{i}_\theta$$
$$a_r \mathbf{i}_r = \sim 0 \mathbf{i}_r$$

Is the value correct?

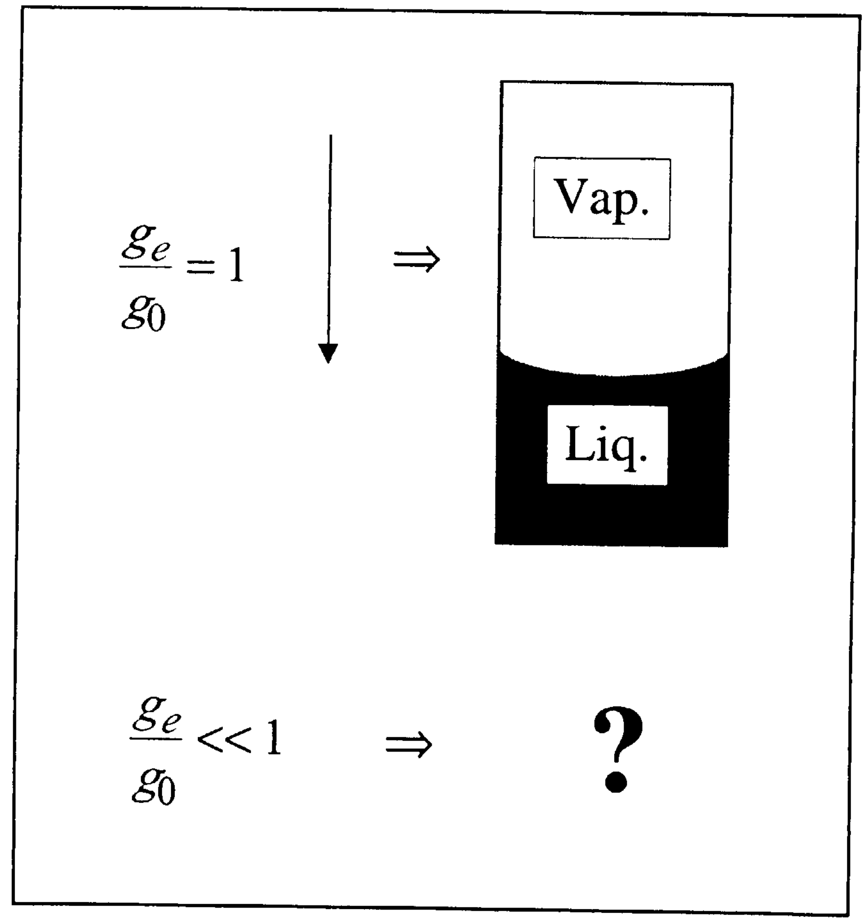
1. It agrees with the SAMS value, but disagrees with the OARE value.
    - Effect on the orbit?
2. Assumption of thermodynamic equilibrium.?
    - Duplicate conditions (temperature and pressure) on the Shuttle in the lab.



Thermodynamic Equilibrium

Confined Fluid in low acceleration field:

- Cylinder with smooth, homogeneous surfaces.
- Partially filled with a liquid.
- If total acceleration is reduced to zero, what configuration does the fluid adopt?



Thermodynamic Equilibrium

Confined Fluid in a low acceleration field:

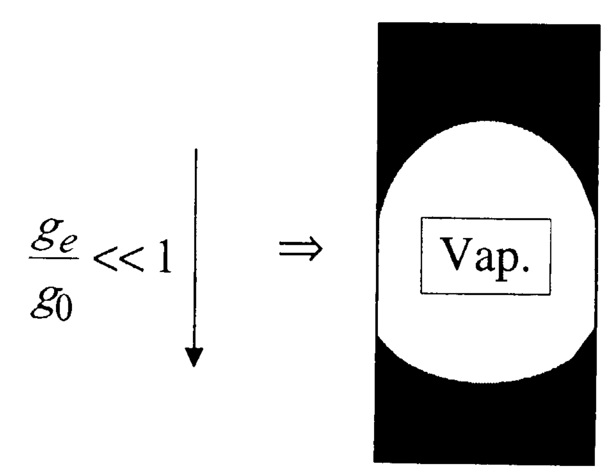
- Surface tension dominates gravitational effects.

- Bond number

$$B = \frac{\rho^L g_e D^2}{4\gamma^{LV}} << 1$$

  Interfaces are approximately spherical

- If $\theta < 36°$, thermodynamically favored configuration is the "two-interface".



Two interface Configuration

Thermodynamic Predictions

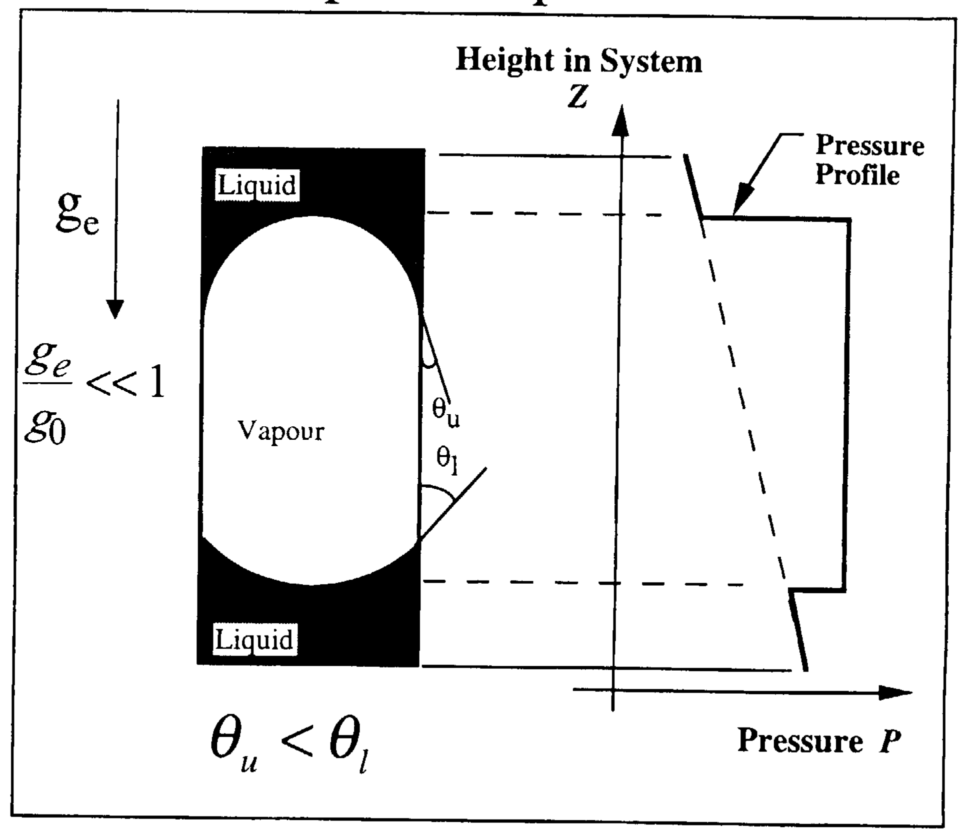
- Conditions for thermodynamics equilibrium:

$$\boxed{\mu^j + Wgz = \lambda, \quad j = L, V, LV, LS, SV}$$

$$P^V - P^L = \gamma^{LV}\left(\frac{1}{R_1} + \frac{1}{R_2}\right)$$

$$\gamma^{SV} - \gamma^{SL} = \gamma^{LV}\cos\theta$$

- Predicted pressure profile!



Are Thermodynamic Predictions Correct?

- Measure H_u, H_l, h_u, h_l

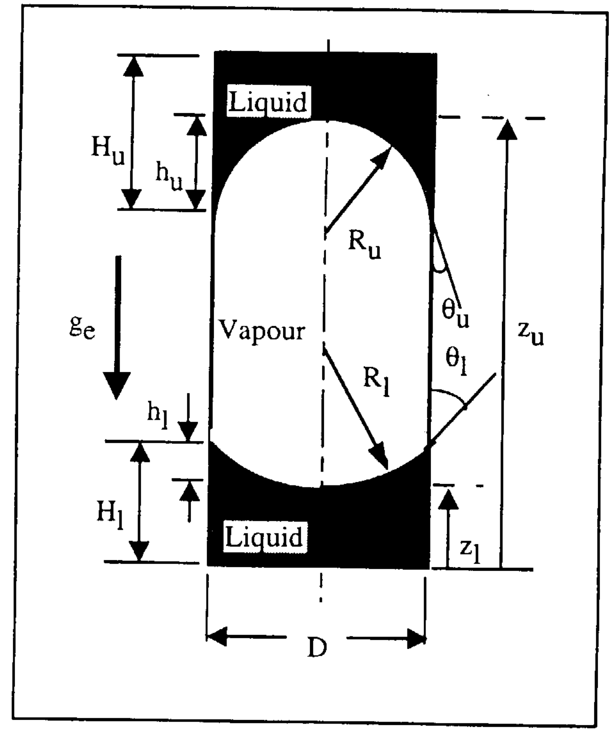
- Contact Angles:

$$\cos\theta_k = \frac{Dh_k}{(\frac{D}{2})^2 + (h_k)^2}, \qquad k = u \text{ or } l$$

- Radius of Curvature:

$$R_k = \frac{(\frac{D}{2})^2 + (h_k)^2}{2h_k}, \qquad k = u \text{ or } l$$

- Acceleration, g_e



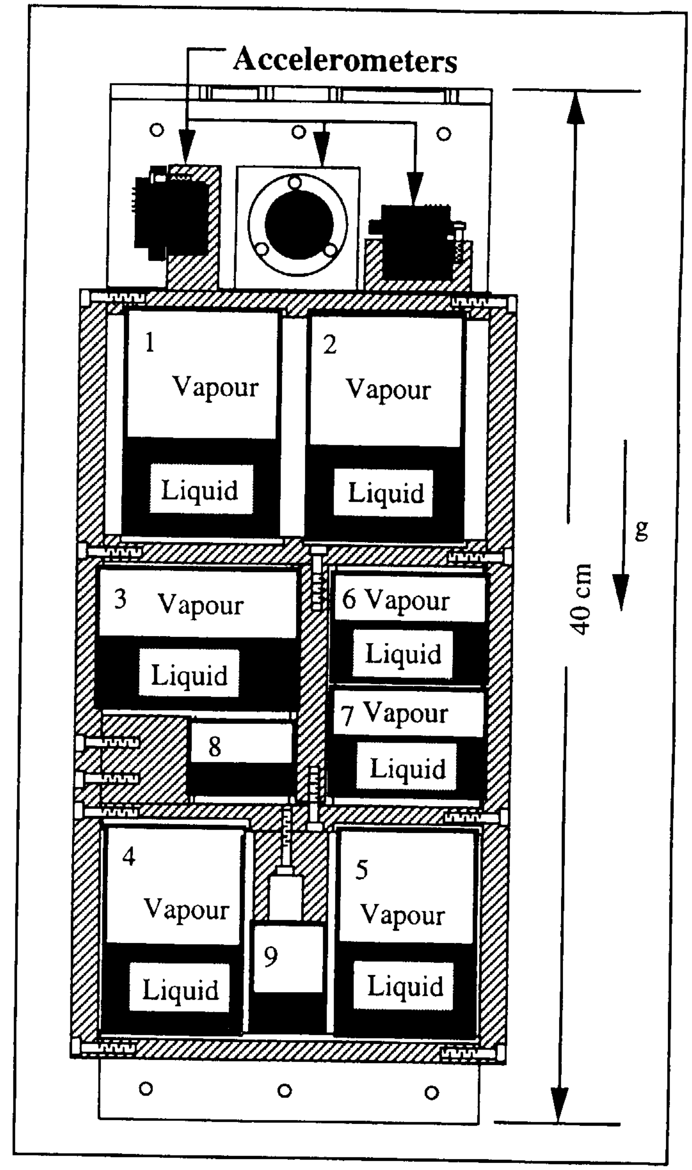
$$g_e = \frac{\gamma^{LV}}{\rho^L_{sat}(z_u - z_l)}\left(\frac{4h_u}{(\frac{D}{2})^2 + h_u^2} - \frac{4h_l}{(\frac{D}{2})^2 + h_l^2}\right)$$

Are Thermodynamic Predictions Correct?

- Two independent methods for determining the total acceleration, g_e on the space Shuttle:

1. Determine g_e from electronic accelerometers.

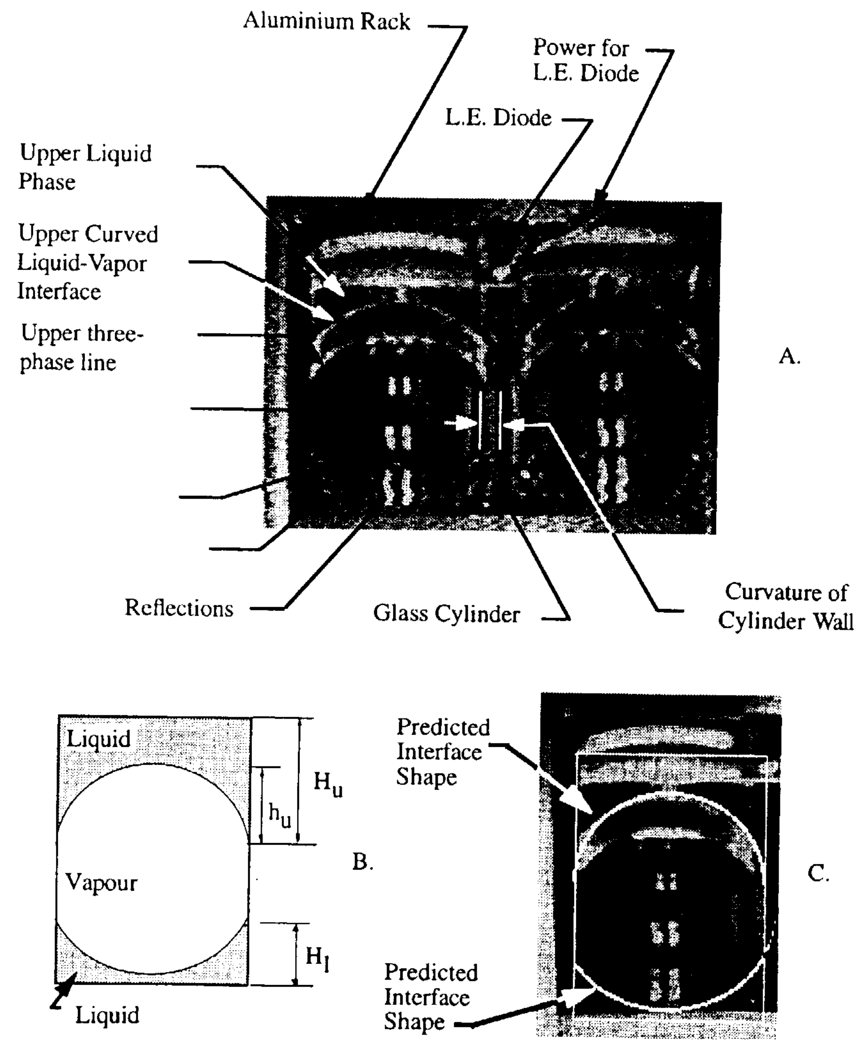
2. And the observed fluid configuration.



Observations from Shuttle Flight STS-87

- Configuration recorded with a video camera
- Measured parameters at 20 different times, 15 seconds apart.
- Contact angle values:

Mean ± SD
$\theta_l = 26.5 \pm 4°$
$\theta_u = 6.7 \pm 1.3°$



Thermodynamic Predictions are Consistent with other Measurements

- Total acceleration calculated during the Shuttle flight, determined from observed fluid configuration:

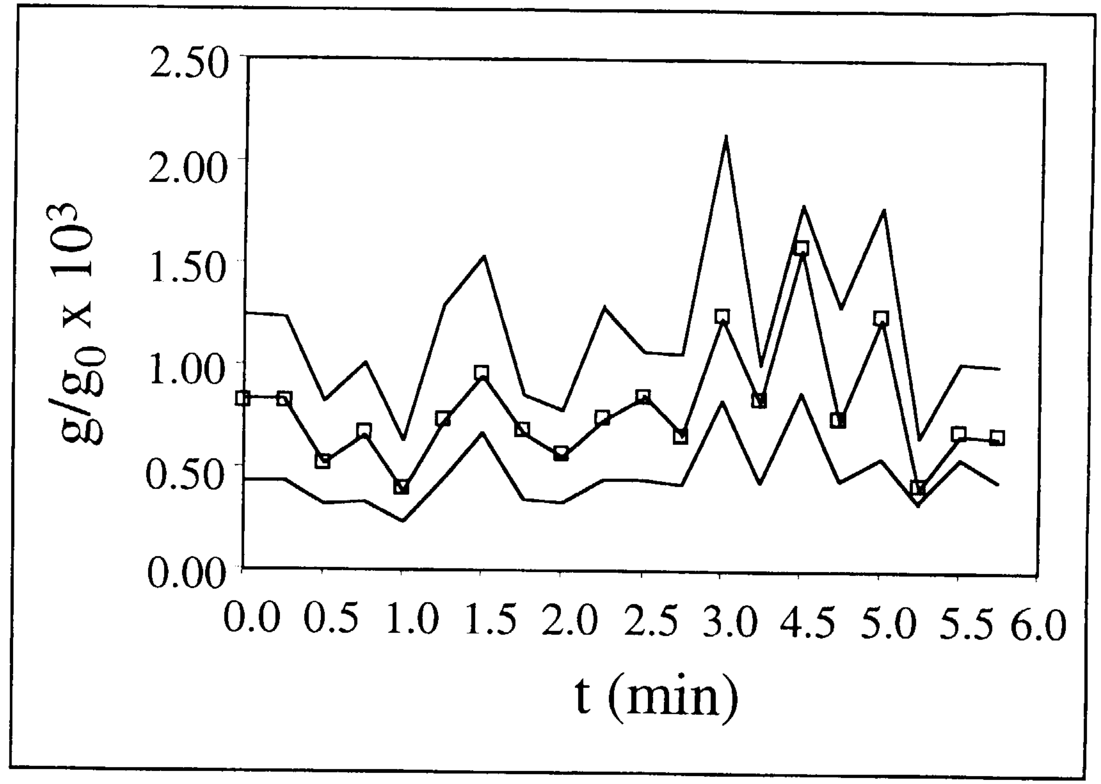
  Mean ± SD

  $$\frac{a_d}{g_0} = (8.0 \pm 3.0) \times 10^{-4}$$

- Total acceleration determined from the Space Acceleration Measurement System (SAMS):

  Mean ± SD

  $$\frac{\mathbf{a_d}}{\mathbf{g_0}} = (6.7 \pm 0.75) \times 10^{-4}$$



Total acceleration determined from the Orbital Acceleration Research Experiment (OARE):

Mean ± SD

$$\frac{a_d}{g_0} = (-0.6 \pm 0.3) \times 10^{-6}$$

Thermodynamic Conditions at the Three-Phase Lines

- On the Shuttle

Upper: $\Rightarrow \dfrac{P_{sat} - P_l^V}{P_{sat}} = 3.5 \times 10^{-8}, \theta_l = 26.5°$

Lower: $\Rightarrow \dfrac{P_{sat} - P_u^V}{P_{sat}} = 4.1 \times 10^{-8}, \theta_u = 6.7 \pm 1.3$

Young equation: $\gamma^{SV} - \gamma^{SL} = \gamma^{LV} \cos\theta$

Can these conditions be duplicated in a ground-based laboratory?

Yes, Using a Rotating System

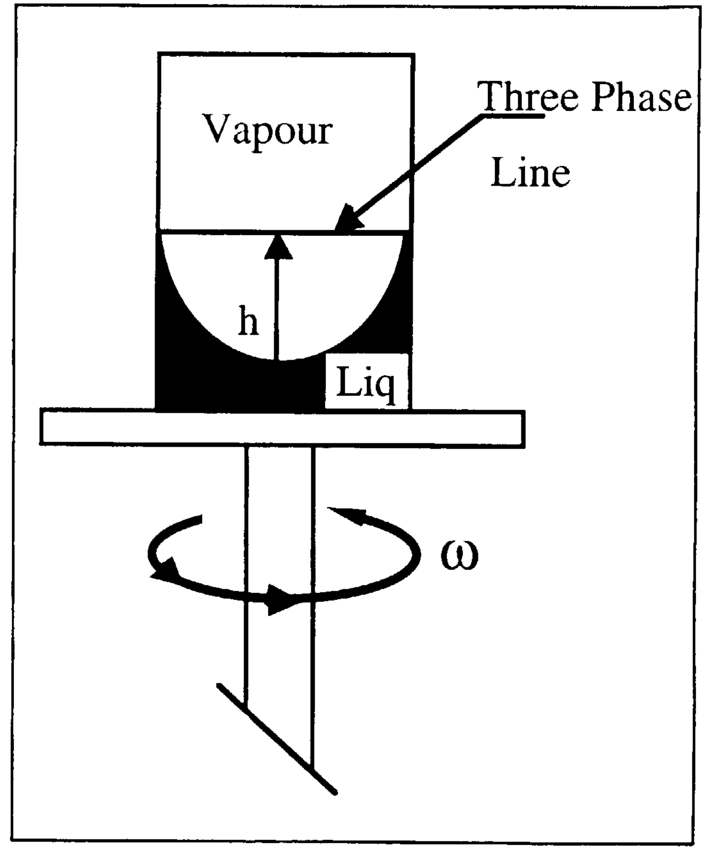
- Conditions for thermodynamic equilibrium:

$$\mu^j + W(gz - \frac{r^2\omega^2}{2}) = \lambda, \quad j = L, V, LV, LS,\ SV$$

$$P^V - P^L = \gamma^{LV}(\frac{1}{R_1} + \frac{1}{R_2})$$

- Measure h, then predict:

  1. $P_{tp}^V = P_{tp}^V(h)$,
  2. $\theta = \theta(h)$



Experimental Apparatus

$$\cos\theta - \cos\theta_r = (\frac{\bar{R}Tn_m^{SV}}{\gamma^{SV}})\ln[(1 - P^V / P_{sat})/(1 - P_r^V / P_{sat})]$$

Results from Rotating System

- Best fit value for n_m^{SV}

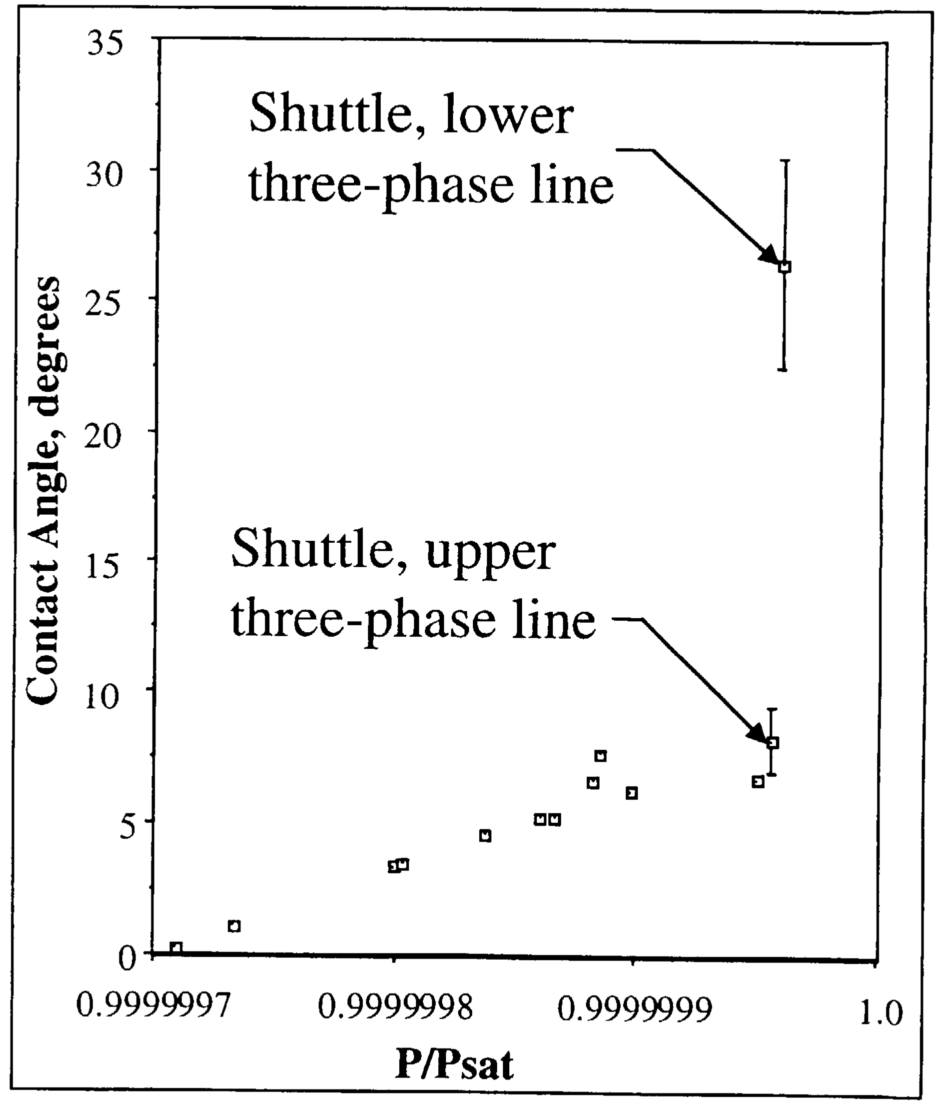
  $\theta_r = 1.07429°$,

  $P_r^V / P_{sat} = 0.99999973$,

  $n_m^{SV} = 1.88 \times 10^{-10}\,\mathrm{kmol/m^2}$

- Previously reported by others for H_2O adsorbing on Silica Gel

  $n_m^{SV} = 1.14 \times 10^{-10}\,\mathrm{kmol/m^2}$



If the inferred acceleration is correct, what would be the effect on the orbit?

Integrate the equations of motion

$$-\frac{M}{r^2}\mathbf{i}_r - m_s a_d \mathbf{i}_\theta = m_s\left[\frac{d^2 r}{dt^2} - r\left(\frac{d\theta}{dt}\right)^2\right]\mathbf{i}_r + m_s\left[r\left(\frac{d^2\theta}{dt^2}\right) + 2\left(\frac{dr}{dt}\right)\left(\frac{d\theta}{dt}\right)\right]\mathbf{i}_\theta$$

$$M = \frac{G m_s m_E}{r^2}$$

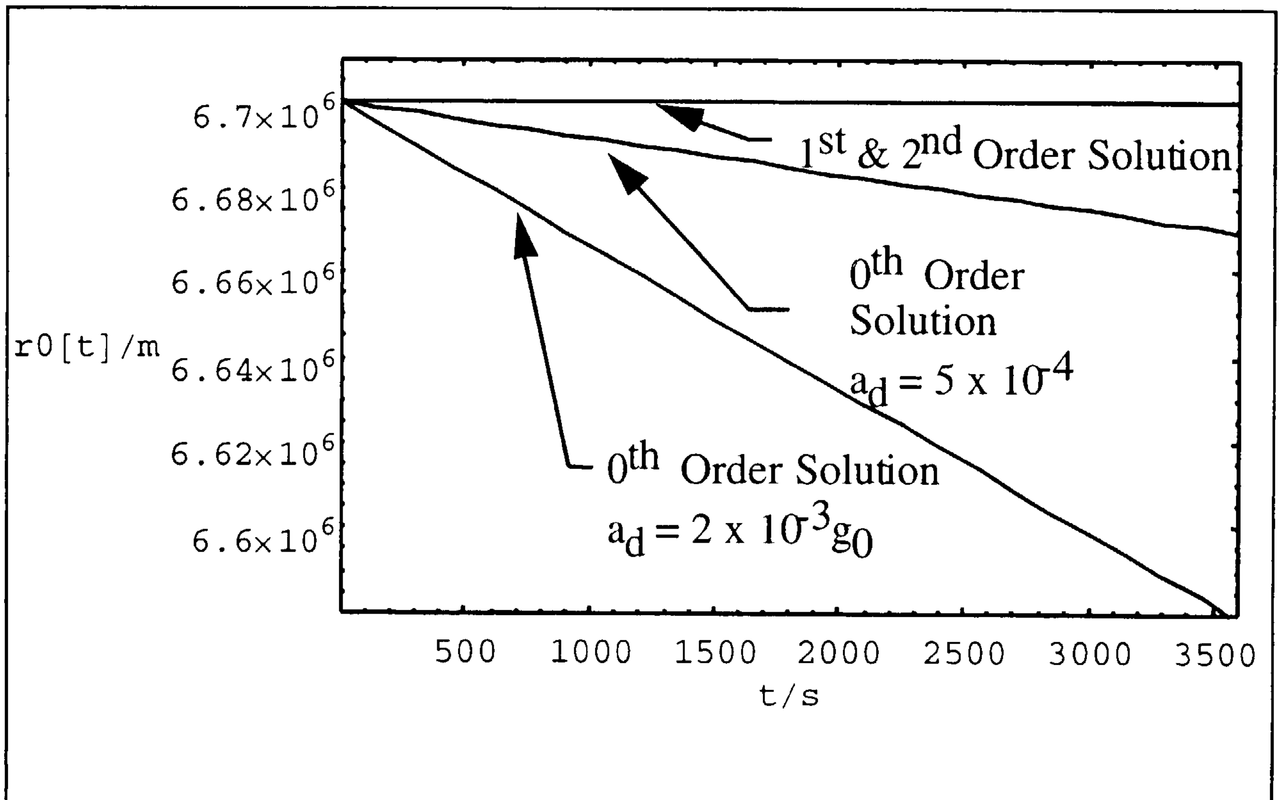
$$\frac{\mathrm{a_d}}{\mathrm{g_0}} = (8.0 \pm 3.0) \times 10^{-4}$$

Obtain an Iterative Solution to the Equations of Motion

$$\frac{d}{dt}\left(\sqrt{r_{j-1}^{3}\frac{d}{dt}\left(\frac{dr_{j-1}}{dt}\right)+\frac{M}{m_S}r_j}\right)=-a_d r_j$$

$$r_j(0)=0$$

Calculate orbit radius as a function of time.



Summary and Conclusion

1 In the Space Shuttle experiment, the contact angle at thelower three-phase line was observed to be greater than that at the upper three-phase line by $19.8 \pm 5.3°$.

2 Assuming thermodynamic equilibrium, the measured drag-induced acceleration can be determined from the values of the contact angles. The value agrees with SAMS measurement, but not with the OARE value.

3 The thermodynamic conditions at the upper three-phase line of the Shuttle experiment can be reproduced in ground-based experiments. Results to-date coincide.

4 The acceleration inferred from the fluid cell is too small to affect the Shuttle orbit.

5 To predict the configuration that a confined fluid will adopt on the Shuttle, the OARE-indicated acceleration is of questionable validity.

59/34

2001017...

512570
39p

Paper Number: 9

Effects of g-jitter on diffusion

Bjarni Tryggvason
Canadian Space Agency
St. Hubert, Quebec, Canada

The Microgravity Vibration Isolation Mount (MIM) developed by the Canadian Space Agency (CSA) has been used on the Mir space station and the US space shuttle to investigate the effect of g-jitter on liquid diffusion. The first version, MIM-1, flew on the Mir space station and was operated for over 3000 hours including approximately 100 experiments on diffusion in liquid metals. The second version, MIM-2, flew on shuttle mission STS-85 and was used to support several fluid science experiments including one on the effect of Brownian motion. Another experiment conducted on the Mir using the MIM was one that looked at nucleation in glasses and the impact of g-jitter on this. These three sets of experiments all show an effect of g-jitter on the results. Of significance is that the sensitivity to g-jitter was at levels that are typically well below the current International Space Station (ISS) vibratory specification. The main results of these experiments will be presented along with the g-jitter levels.

Effects of G-Jitter on Diffusion

Results from Mir, STS-85 and Ground Based Experiments

Bjarni V. Tryggvason
Canadian Space Agency

MGMG 19 July 11, 2000

Background

- Measurements of diffusion in metals from experiments performed on Mir show sensitivity to g-jitter
- Basis for diffusion is Brownian motion
- Sensitivity of Brownian motion to temperature extensively studied over the years

Experiment Objective

- Examine effect of g-jitter on Brownian motion
- Look at Brownian motion under
  - Latched mode
  - Isolated mode
  - Driven mode
    - Sinusoidal
    - Random broad band

Experiment Method

- Recorded video of particle motion
  - cell with density matched 1-micron seed particles
  - cell with density matched 5 microns seed particles
- Post flight analysis
  - track random motion of many particles to determine average particle displacement over time
  - compare to theoretical predictions

Qualitative Observations

- Particle motion clearly visible
  - random motion
  - correlated motion during non-isolated and driven mode operations
  - **correlated motion contradicts expectation of many in the micro-g fluids community and needs to be verified**

Quantitative Observations

Table 1: Five microns particles

At 25°C, the theoretical diffusion coefficient for 5 microns particles is 0.0971 $\mu m^2/s$

MIM mode	N	Duration (seconds)	Diffusion coefficient ($\mu m^2/s$)
Isolation	7	153.08	0.0314
Random vibration	5	152.74	0.0673
1Hz sine wave vibration	8	152.37	0.0405

Table 2: One micron particles

At 25°C, the theoretical diffusion coefficient for 1 microns particles is 0.4856 $\mu m^2/s$

MIM mode	N	Duration (seconds)	Diffusion coefficient ($\mu m^2/s$)
Isolation	47	110.24	0.0405
Random vibration	N/A	N/A	N/A
1Hz sine wave vibration	N/A	N/A	N/A

Figure 1 : 5 microns - Isolated mode

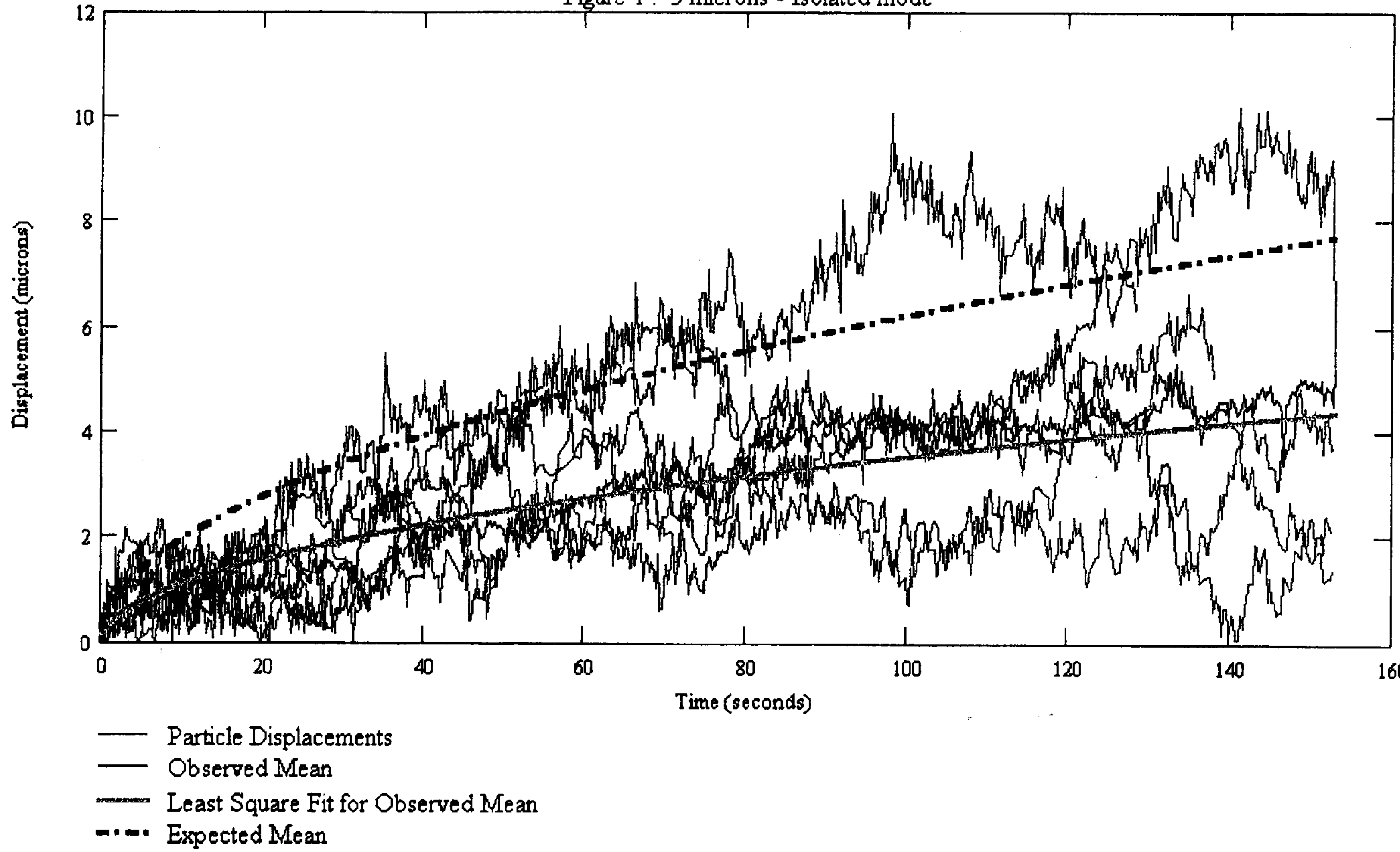
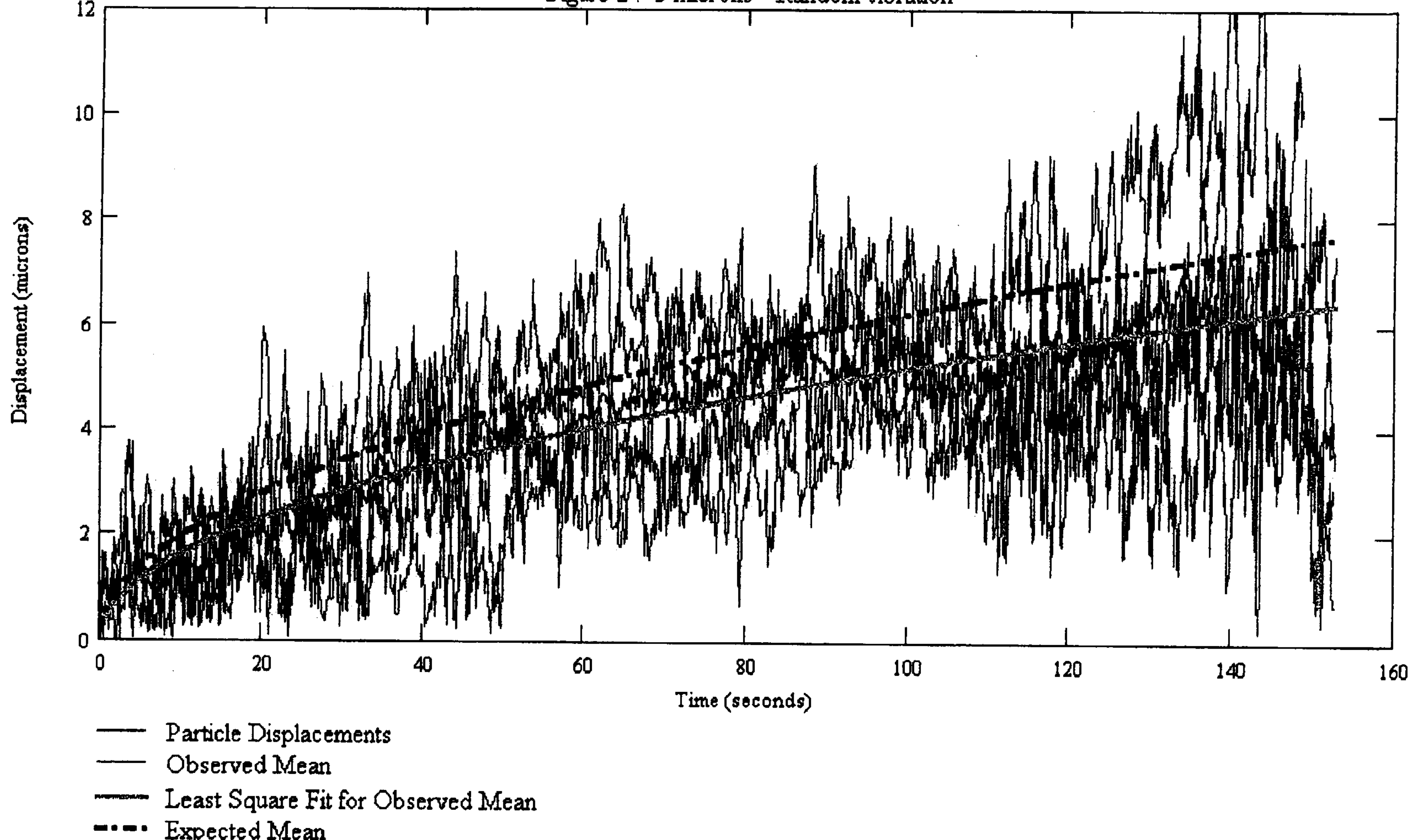


Figure 2 : 5 microns - Random vibration



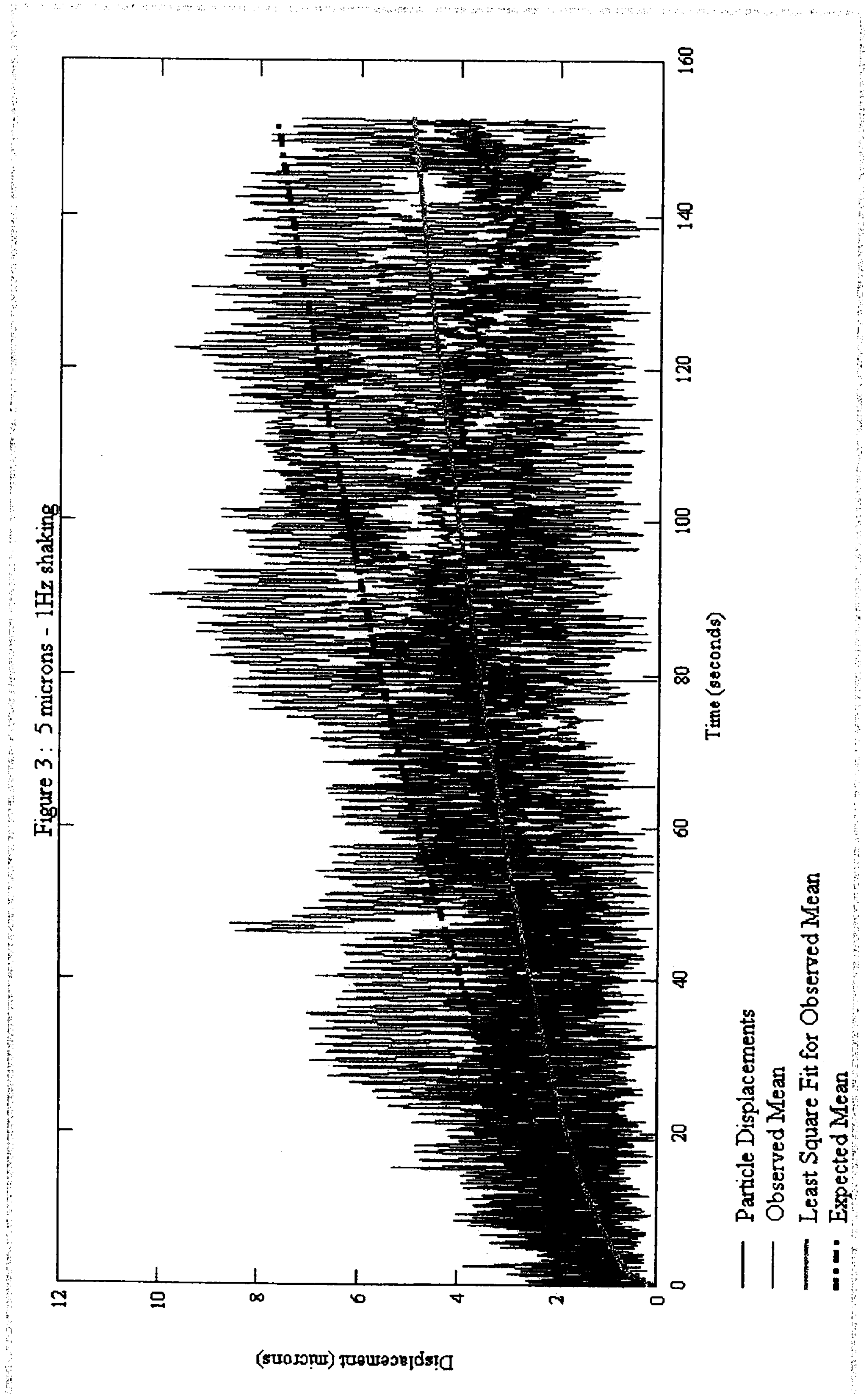
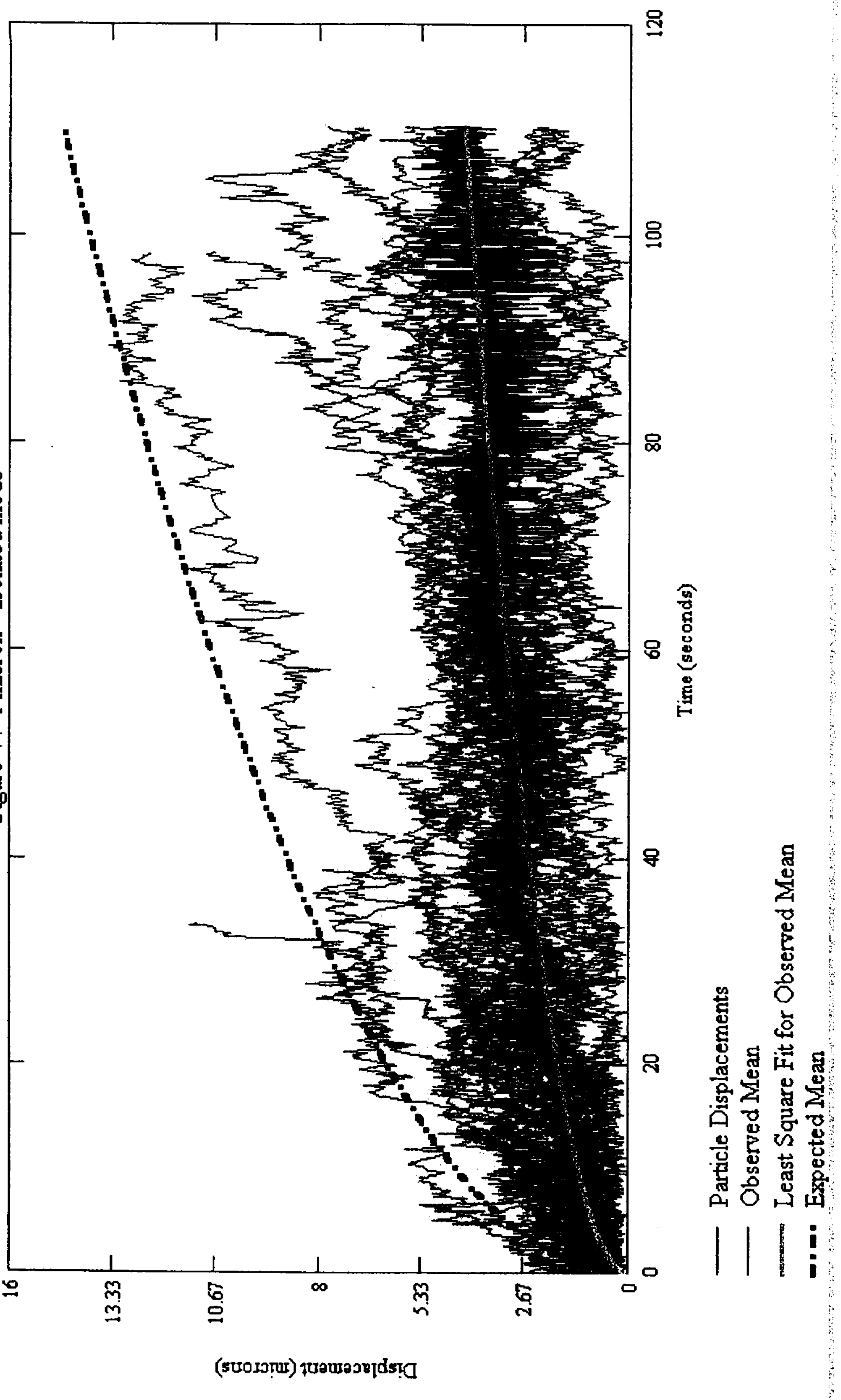


Figure 3 : 5 microns - 1Hz shaking

Figure 4 : 1 micron - Isolated mode



Discussion

- As predicted particle drift progresses with the square root of time
- Magnitude of average drift is significantly less than predicted
  - unexplained at this time
  - ground based experimental work is under way to examine experimental procedures
- Organized motion needs to be verified through more ground experiments

Ground Based Experiments Conducted Since Dec 1998

- Fluid cell redesigned using quartz and a thick copper enclosure with thermal control:
  - temperature of the copper enclosure maintained at 4C with maximum variation < 0.2C
  - This reduces convection to levels similar to those on orbit
- The fluid cell and its copper housing along with the microscopic lens and video camera are enclosed in a box which is insulated thermally and temperature controlled also to 4C

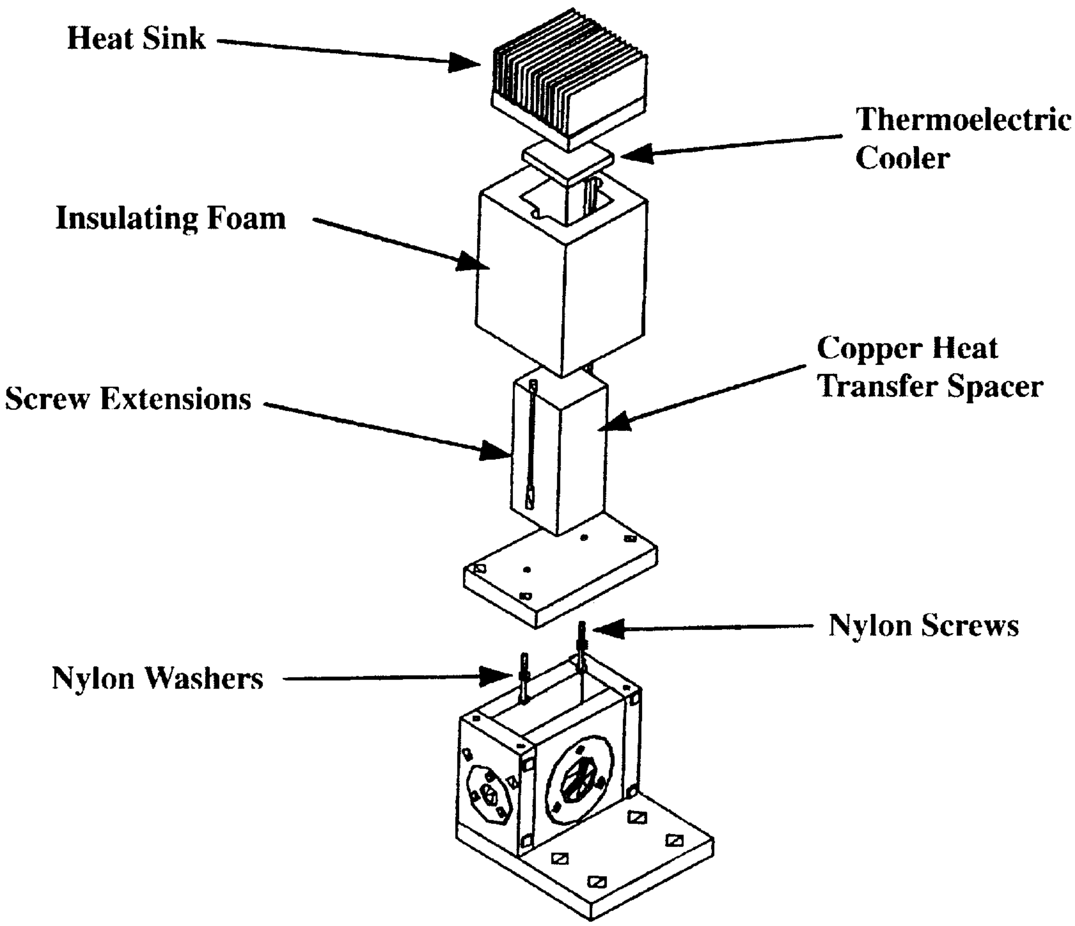


Figure 2. Exploded View of Thermoelectric Assembly

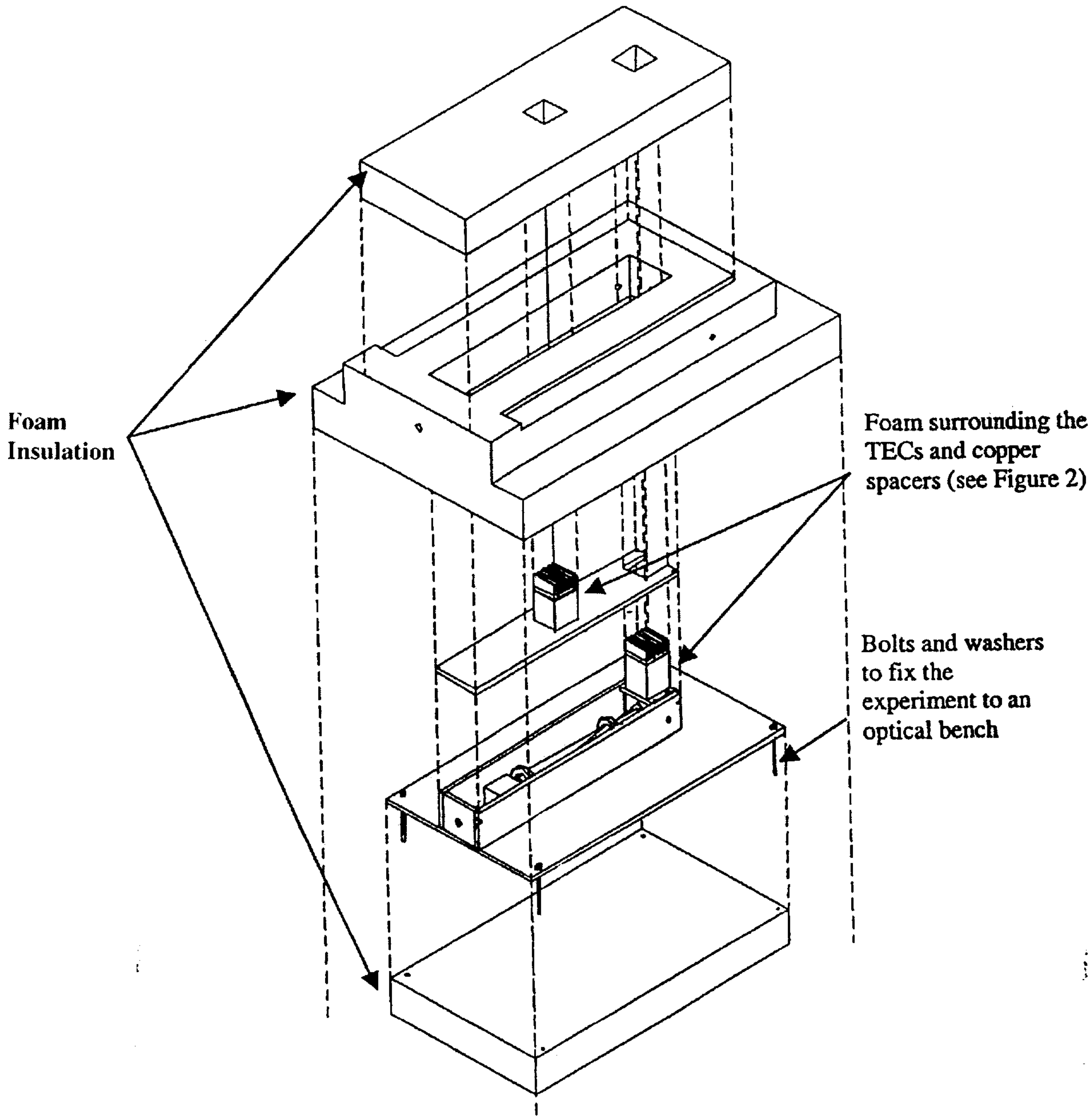
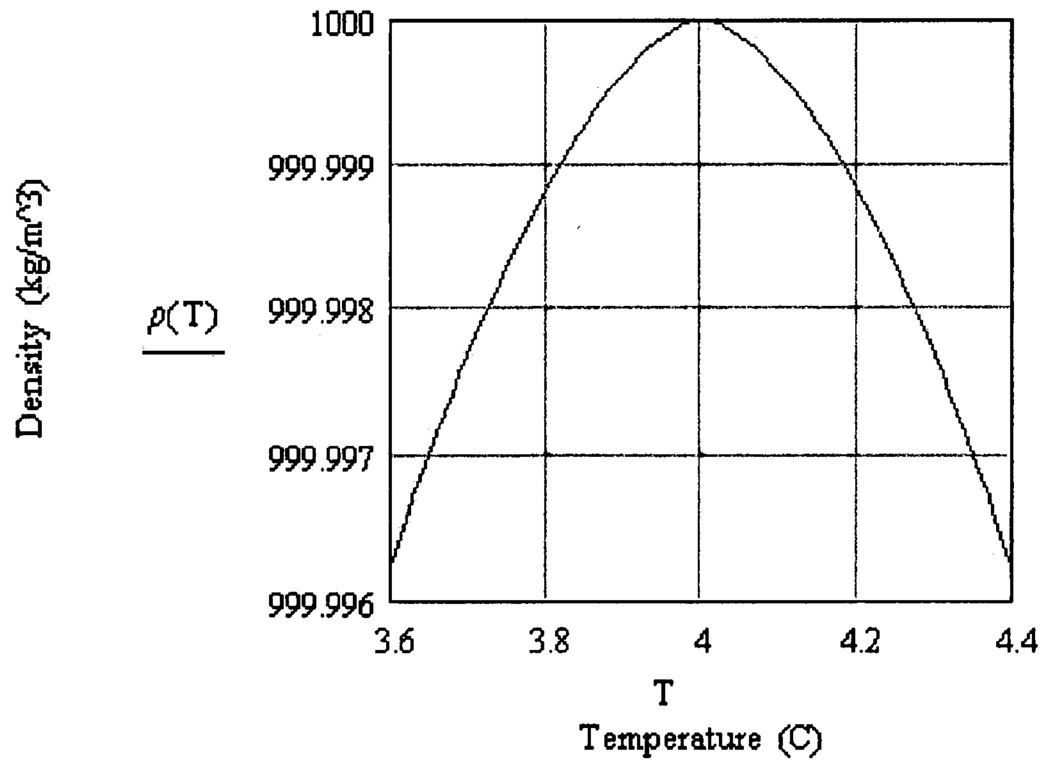


Figure 1. Insulated Brownian Motion Cell

Fluid Cell Thermal Control Requirement



Ground Based Experiments Conducted Since Dec 1998

- The complete setup is mounted on an optical table isolated from building vibrations on a pneumatic suspension system.
- A six DOF electromagnetic based shaker was mounted onto the optical bench. The shaker is a MAGLEV device similar to the MIM.

Density Matching of the Particles to the Fluid

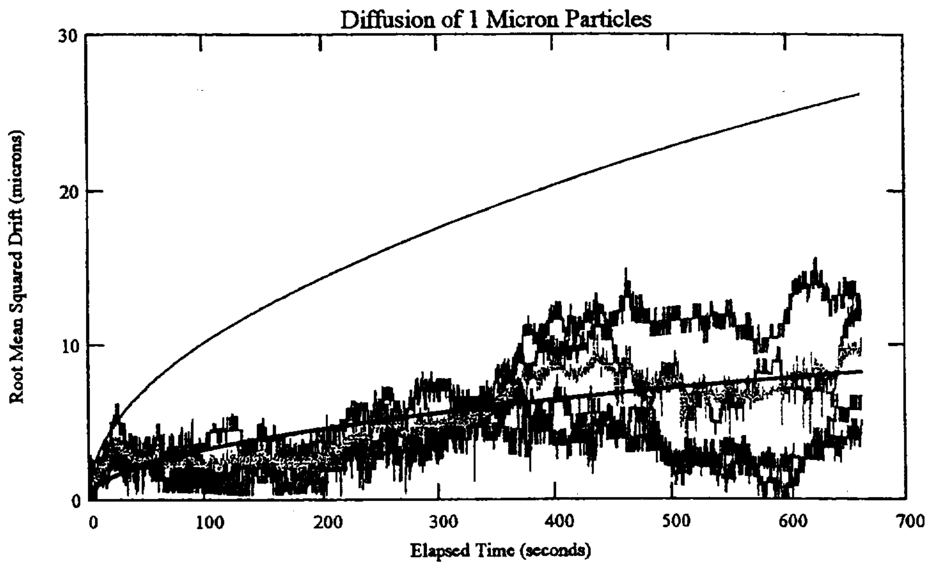
- The fluid cell is filled with distilled water which is sparsely seeded with latex coated polystyrene spherical particles micron in diameter.
  - Particles are the same as those used on orbit
  - Following STS-85 the cells were left standing for more than six months, with no observed settling. After about one year the particles had formed some random chains
  - The cell being used in the current set of ground experiments has shown no settling of the particles over several months

Data Acquisition

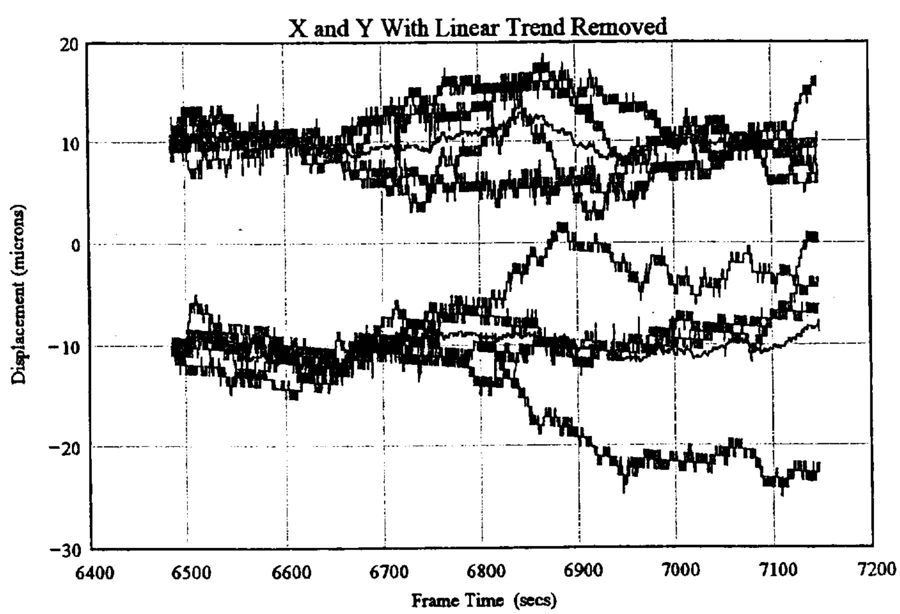
- A commercial image acquisition and analysis board is used to track selected particles. The board provides the coordinates of the selected particles as a function of time. Up to four particles can be tracked at a time at tracking rates of 5 to 7 frames per second.

Partial Summary of Runs

- BWN009 Air bearing not isolating
- BWN010 Air bearing not isolating
- BWN017 Air bearing isolating, random shaking in x,y,z, (1-50Hz) 5mg
- BWN018 Air bearing isolating, random shaking in x,y,z, (1-50Hz) 5mg
- BWN026 Air bearing isolating with 0.05 Hz 3 mg shaking in Y
- BWN092 Air bearing isolating with 0.5 Hz 1 mg shaking in Y
- BWN098 Air bearing isolating with 0.5 Hz 3 mg shaking in Y
- BWN008 Air bearing isolating with 0.5 Hz ? mg shaking in Y



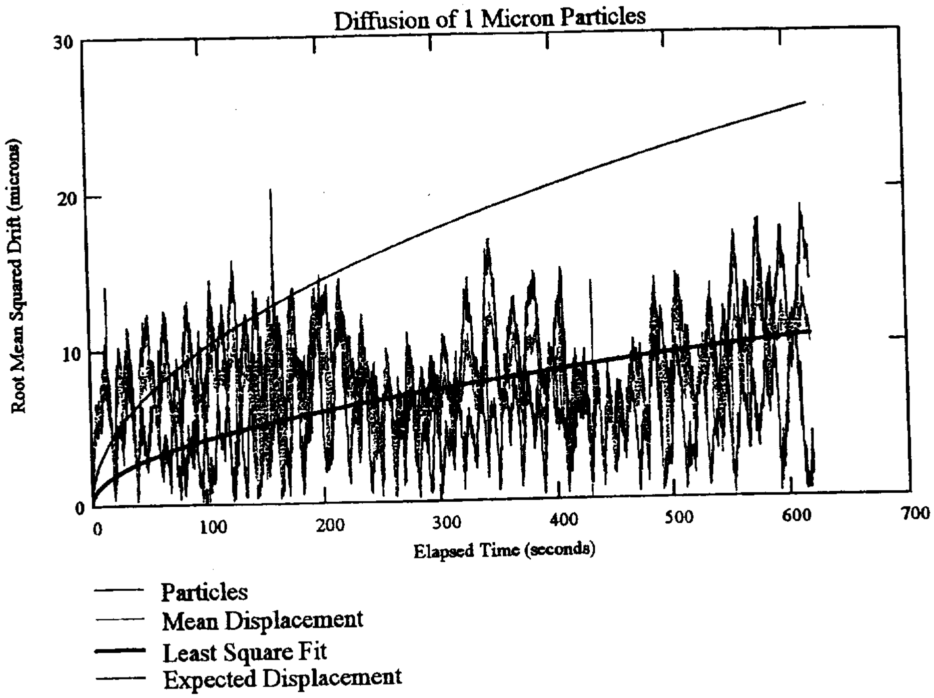
Particles
Mean Displacement
Least Square Fit
Expected Displacement

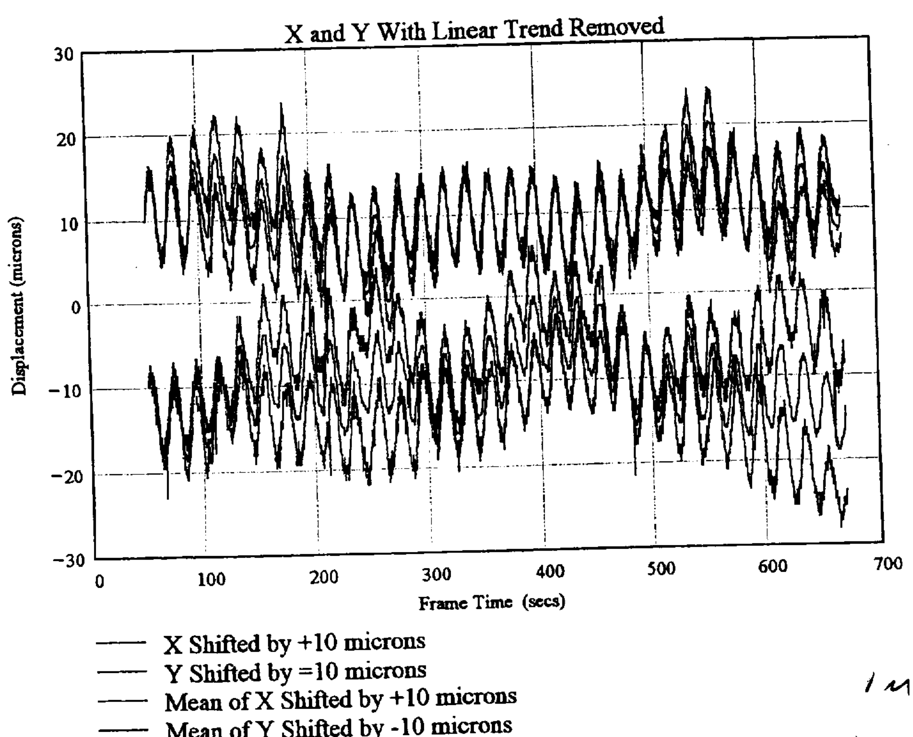


X Shifted by +10 microns
Y Shifted by =10 microns
Mean of X Shifted by +10 microns
Mean of Y Shifted by -10 microns

0.5 Hz @ 1 mg

BWN 026 .05 Hz 3 ug

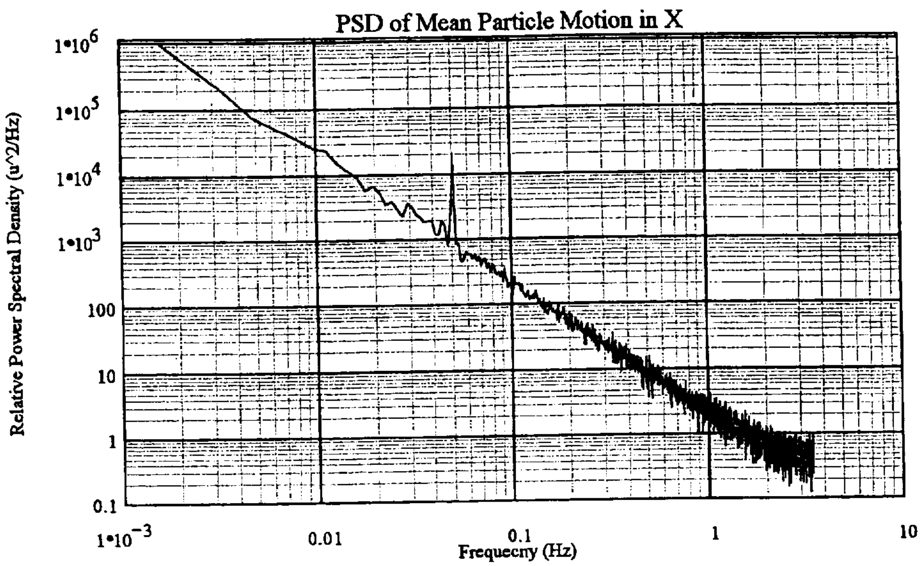


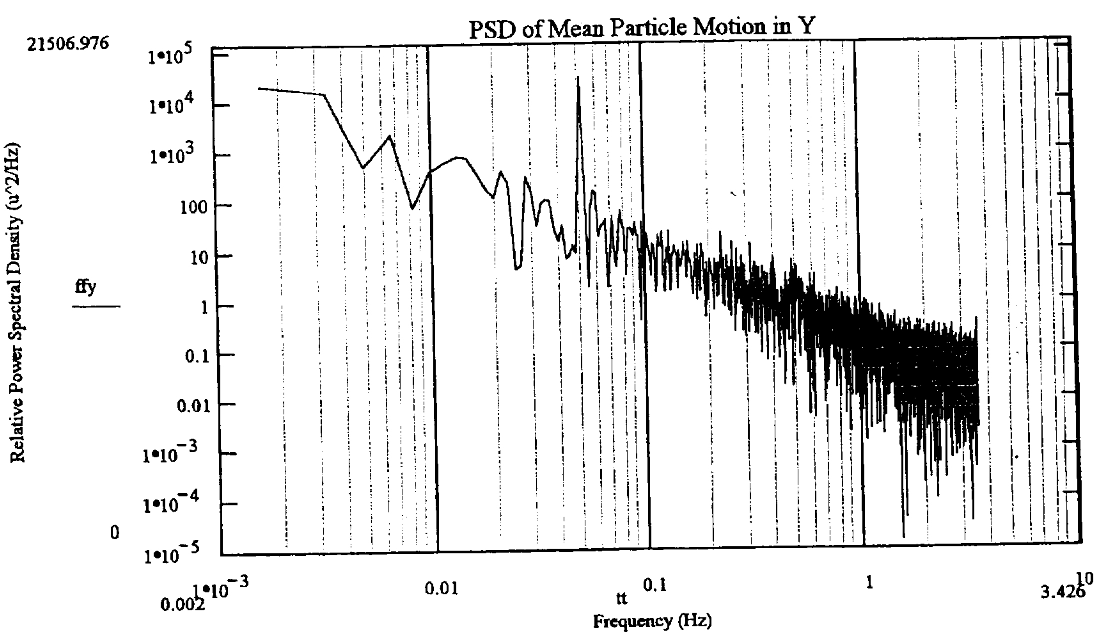


1 μ
0.05 Hz @ 3 mg

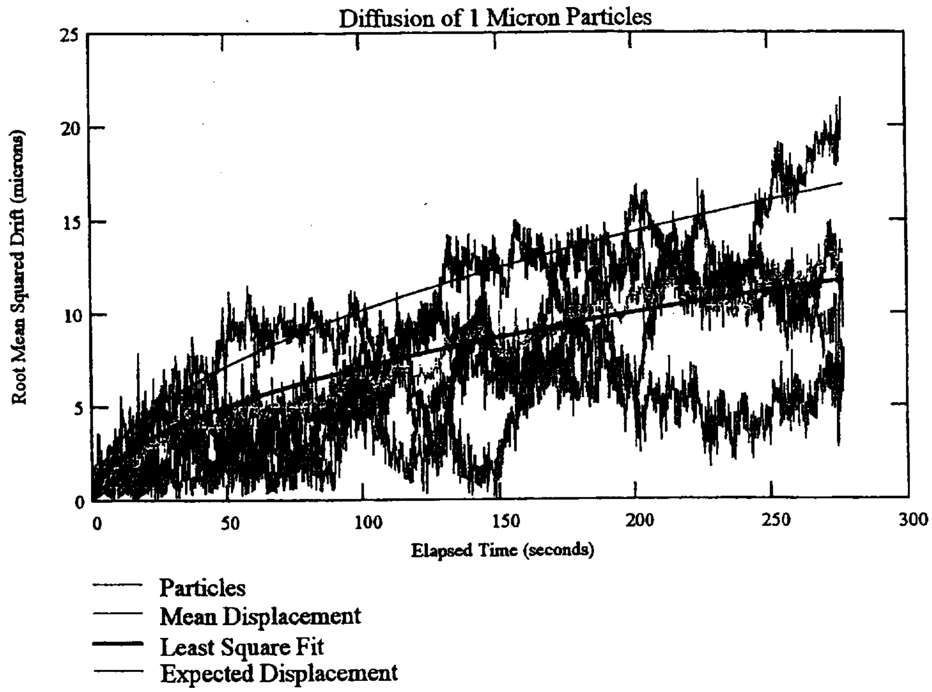
05

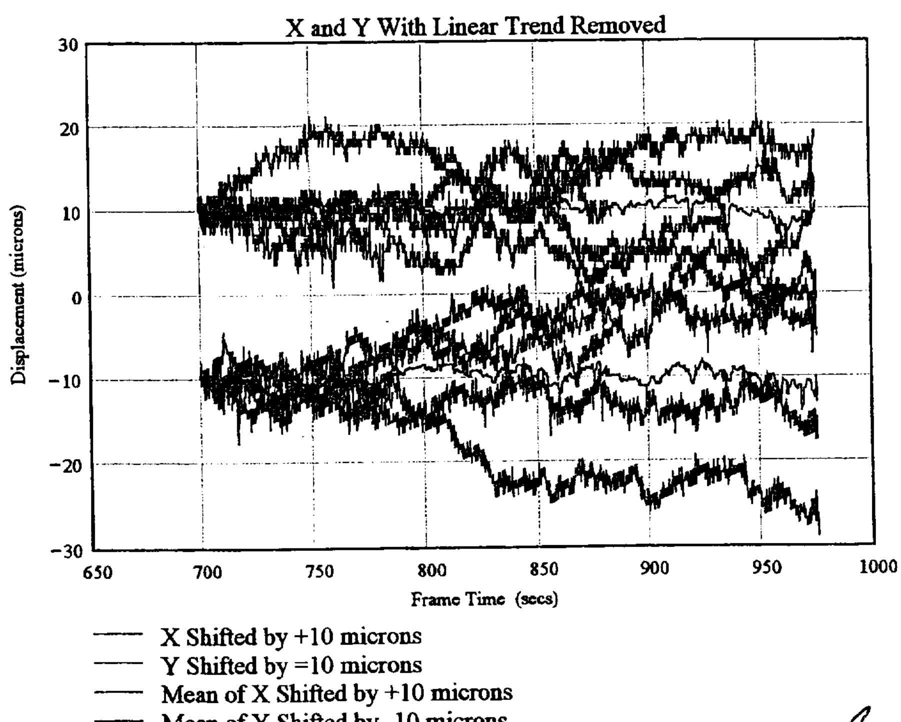
Burnside -00 J



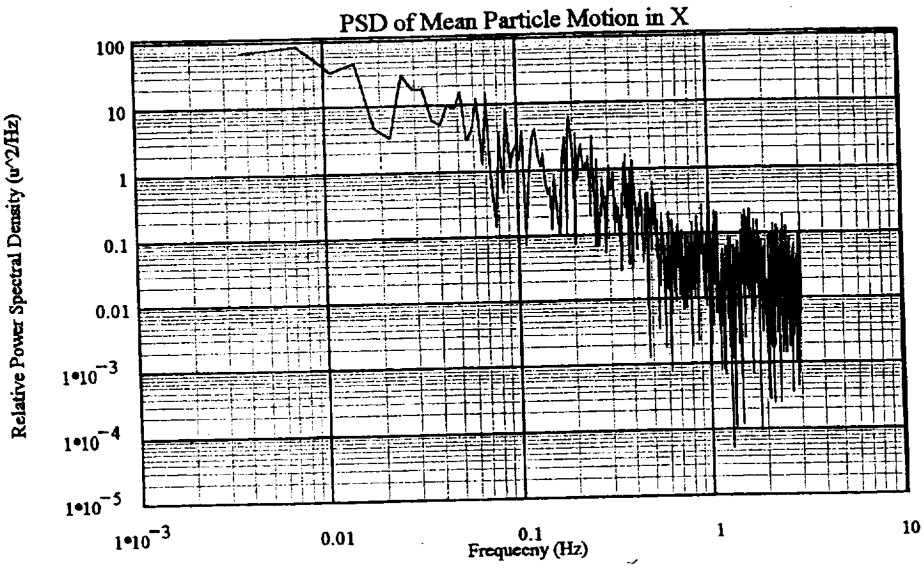


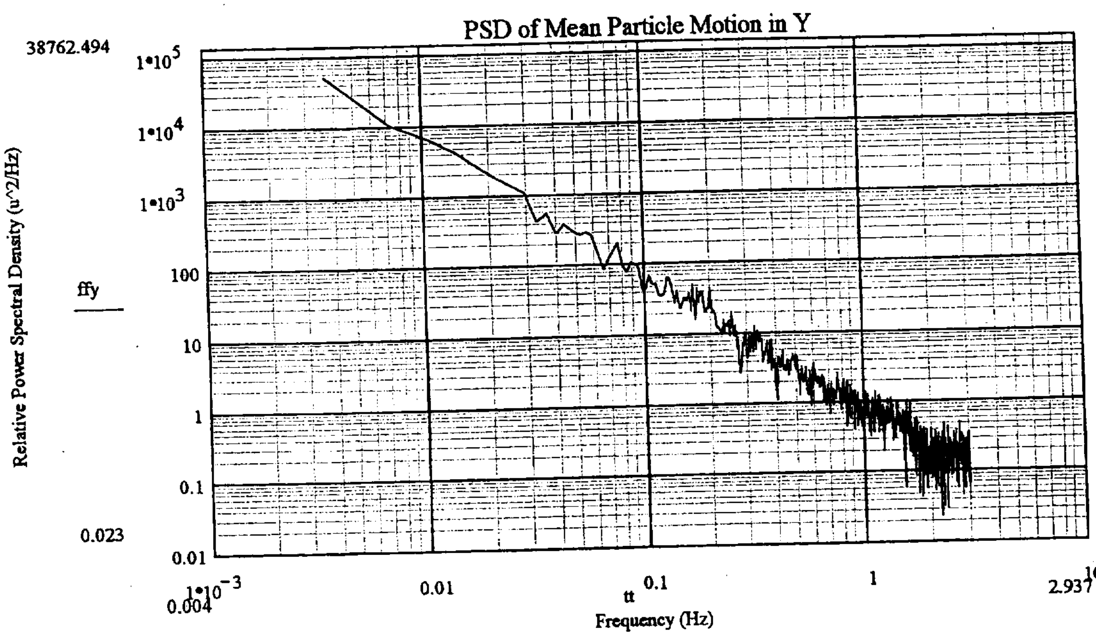
1 M
0.05 Hz @ 3 mg



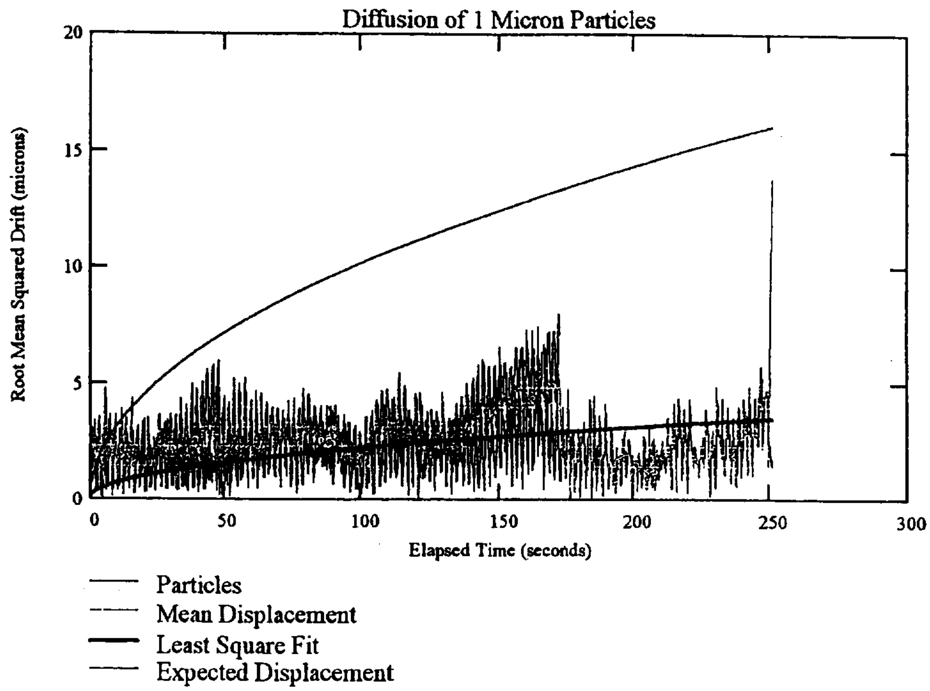


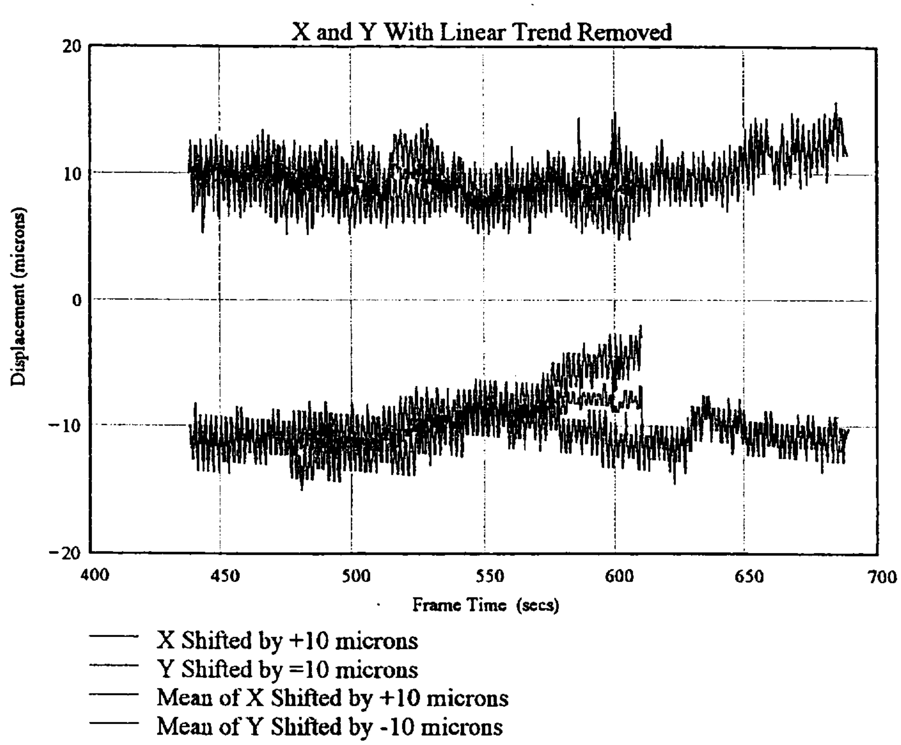
1 μg Random 1-50 Hz.





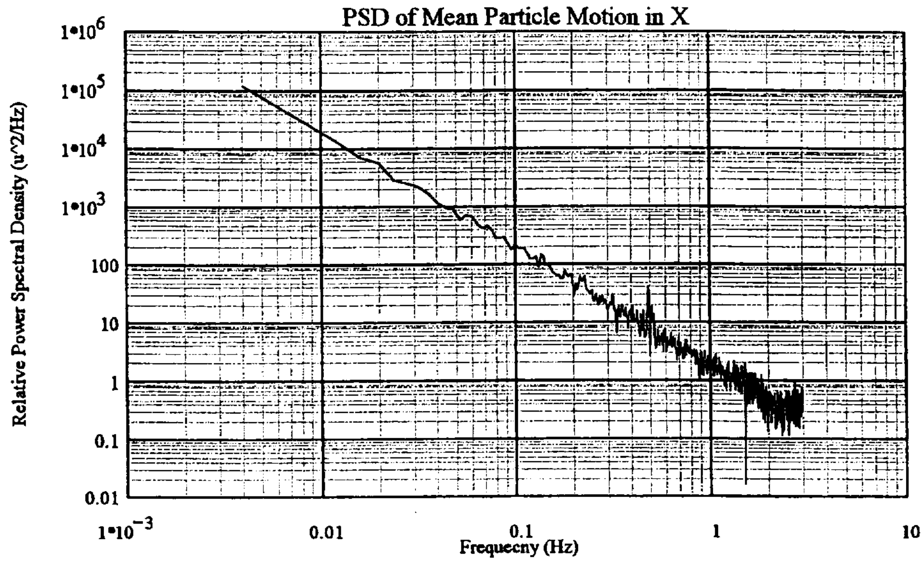
1 m. Random 1-50 1/3

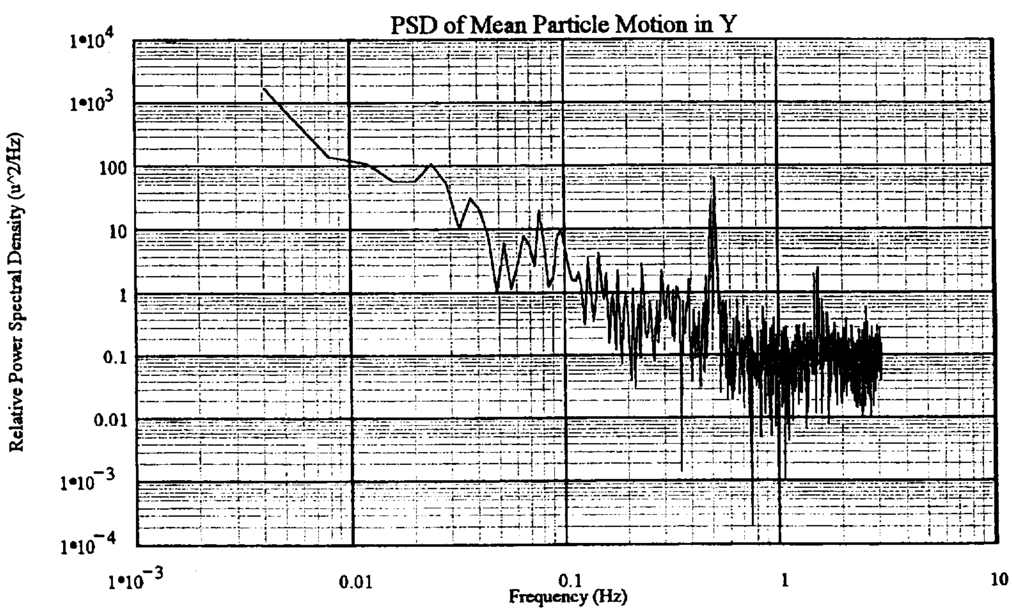




1μ 0.5 Hz @ 3000μg

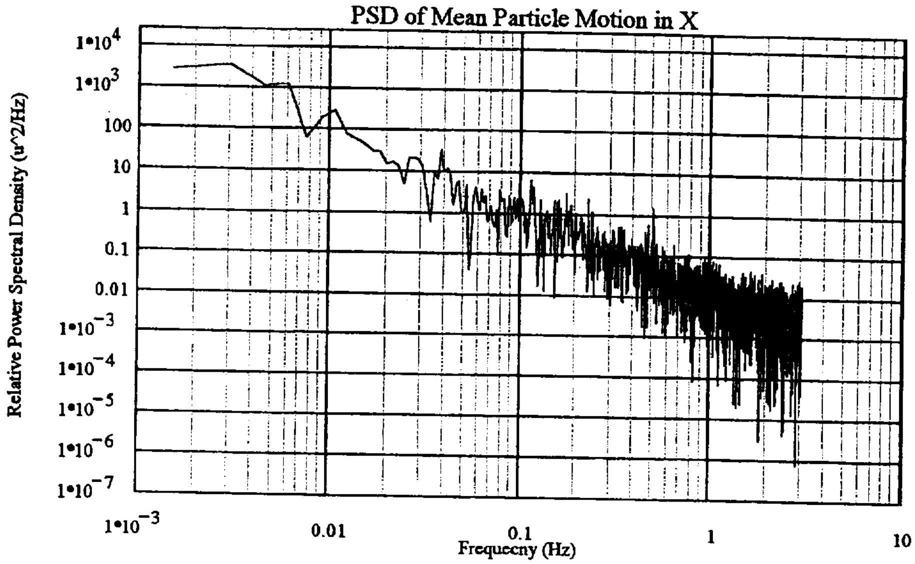
8

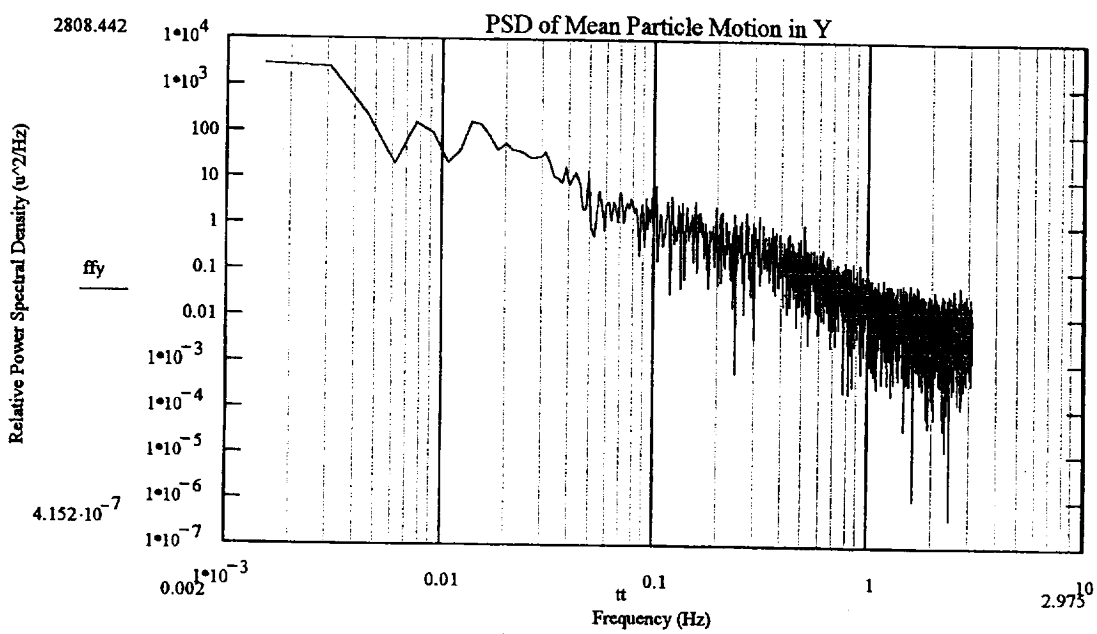




1 μ 0.5 Hz @ 3000 μg

Bwv092 .5Hz 1mg





1u 0.5Hz @ 1000 ug

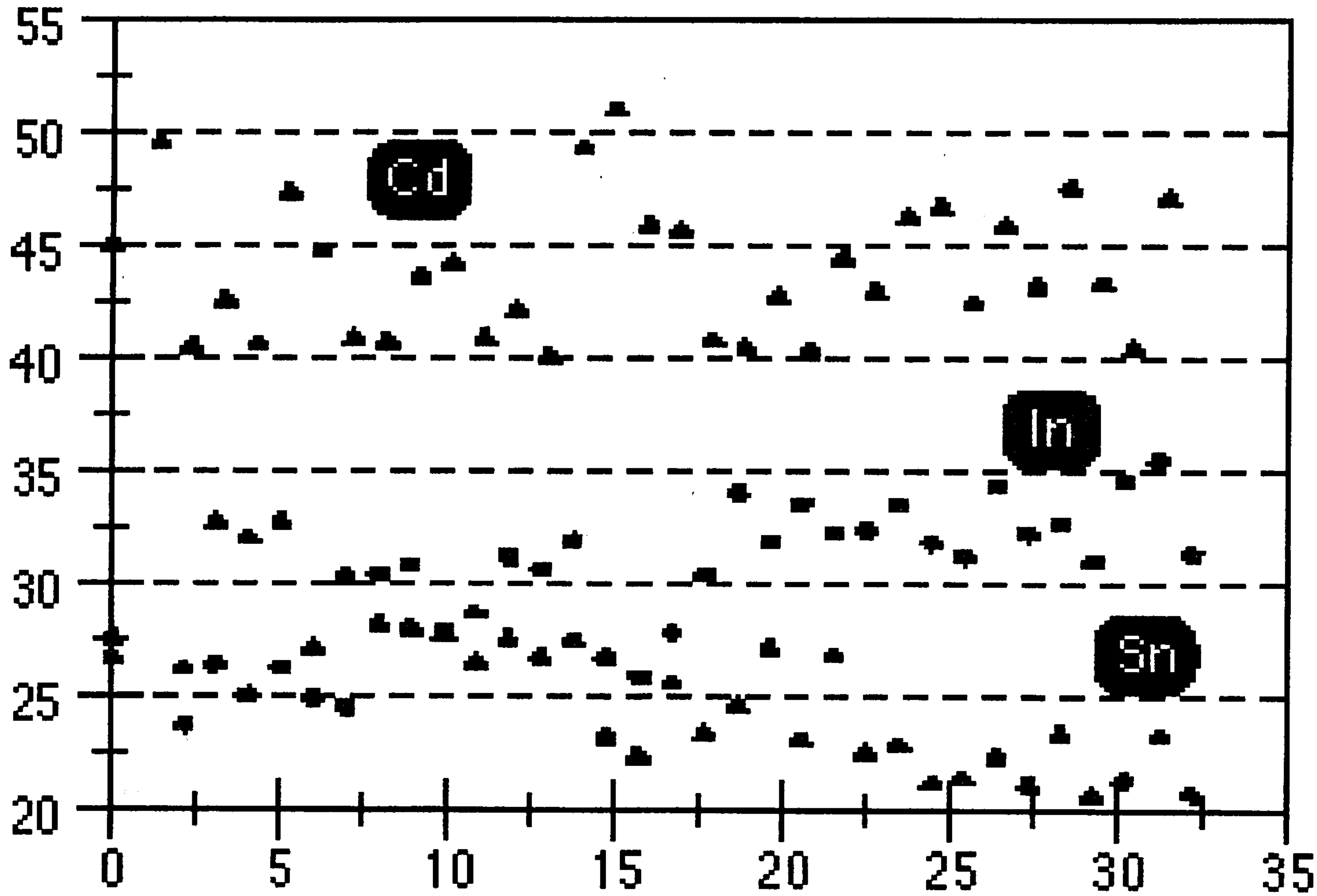
Summary of Ground based Results

- Similar to space based results the diffusion of micron sized particles is less than predicted
- The diffusion does appear to increase with the addition of random vibration. However, additional experiments are still to be conducted to definitively verify this finding.
- There is very clear response to sinusoidal vibrations from 0.05 Hz to 1.0 Hz
- The mechanism for these responses are still to be investigated

$$D_{Measured} = \begin{bmatrix} D_{intrinsic} + D_{buoyancy} + D_{container} \\ + D_{thermal} + D_{Marangoni} \end{bmatrix}$$

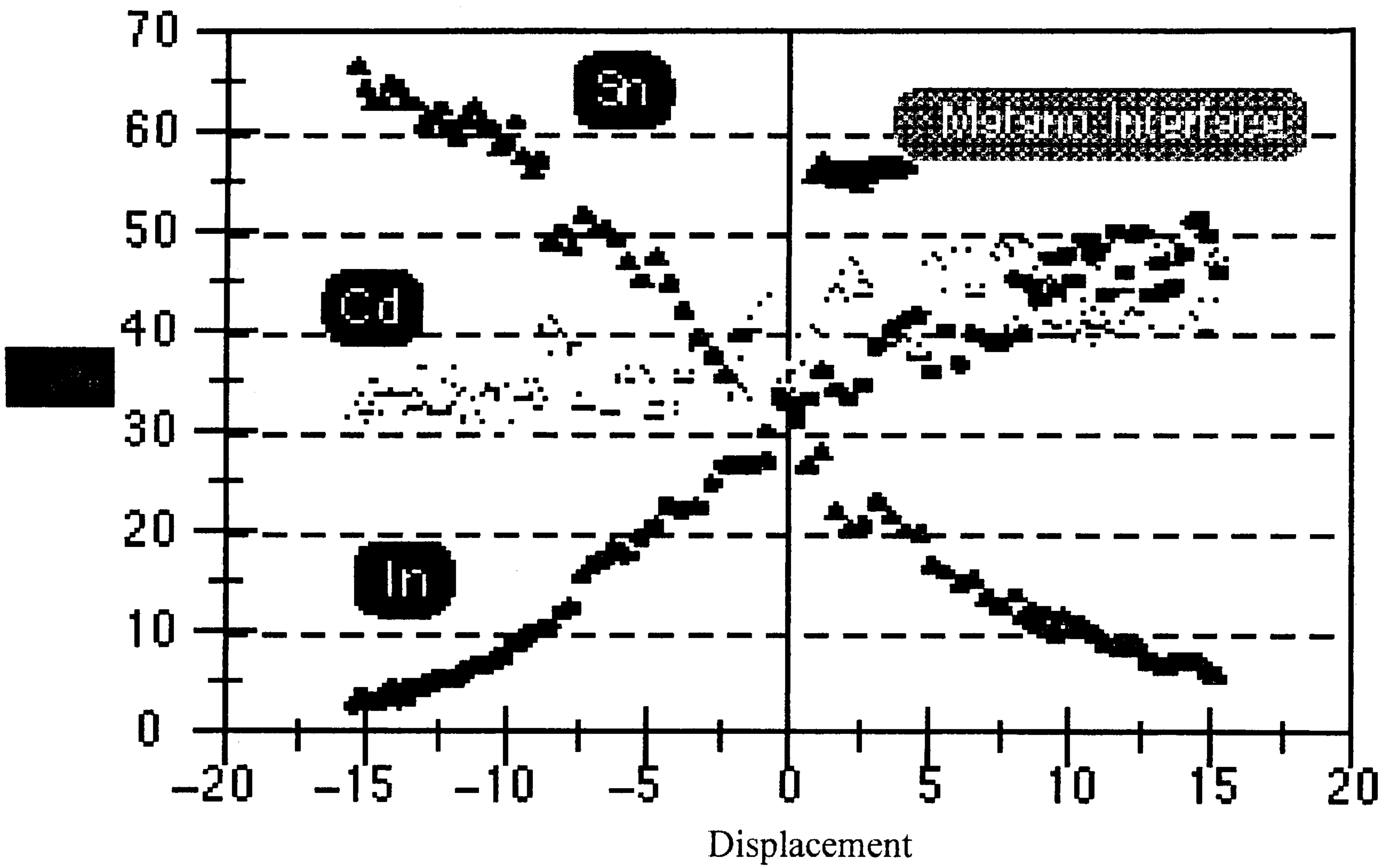
Comparison of Terrestrial and On Orbit Determination of Diffusion Coefficients

Example of CdIn/CdSn diffusion couple specimens processed terrestrially and on orbit at 690 C for 90 minutes

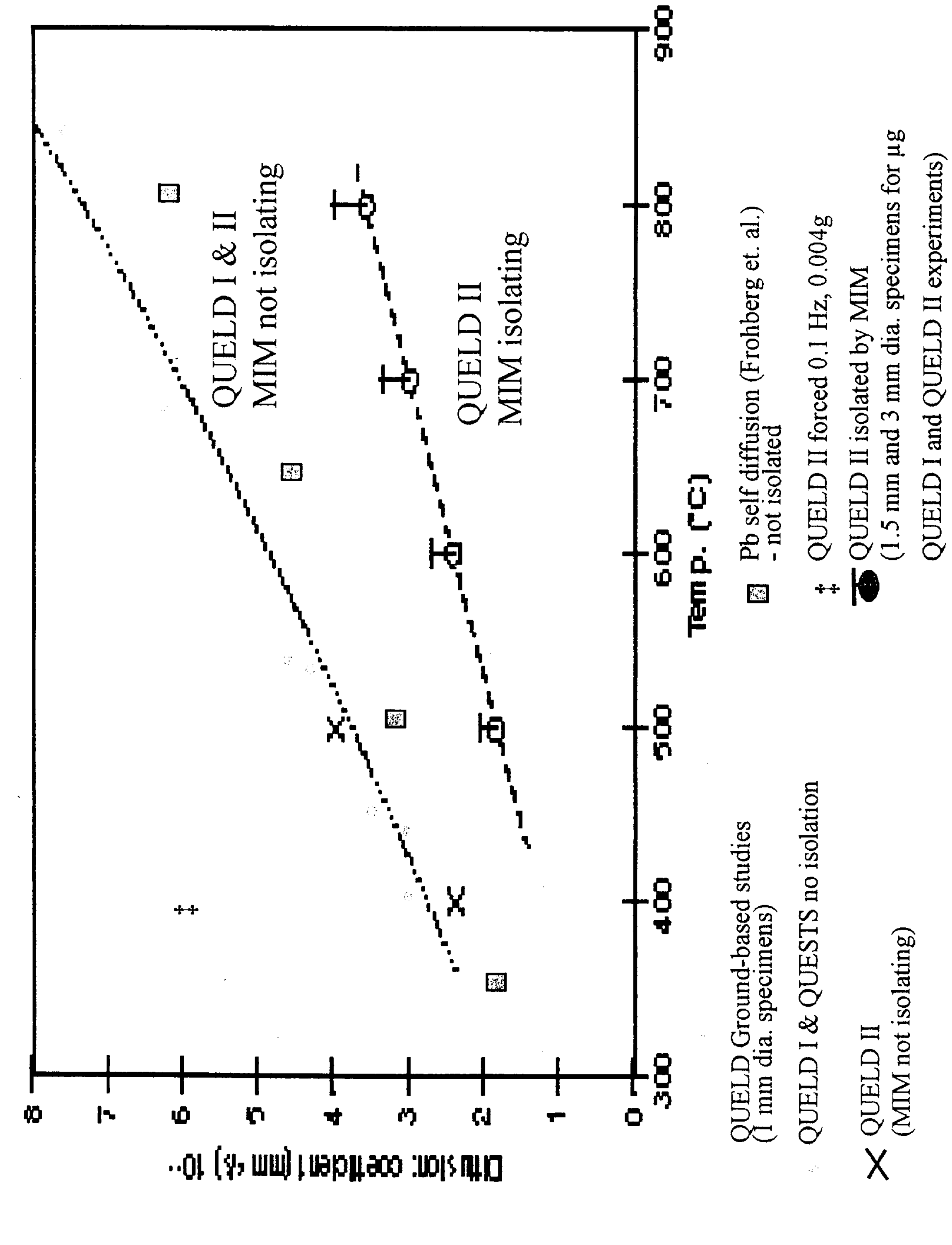


Displacement

Terrestrial liquid-metal diffusion measurements of a CdIn/CdSn diffusion couple specimen at 690 C for 90 minutes [Tandon, Cahoon and Chaturvedi. CSA Interim Report] .

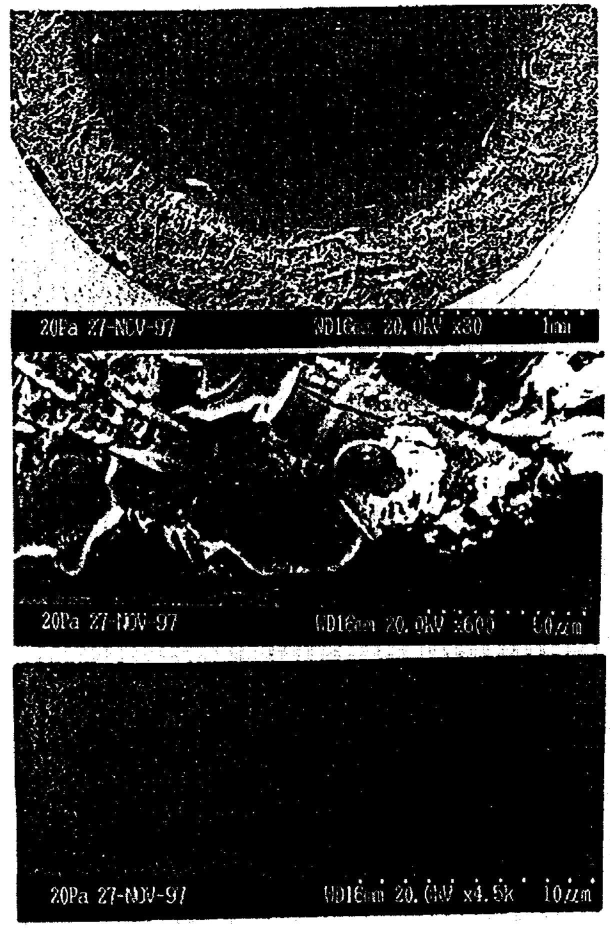


On orbit liquid-metal diffusion measurments of a CdIn/CdSn diffusion couple specimen at 690 C for 90 minutes [Tandon, Cahoon and Chaturvedi. CSA Interim Report].


QUELD I & II
MIM not isolating
QUELD II
MIM isolating
Temp. (°C)
Diffusion coefficient (mm²/s) 10⁻⁹
Pb self diffusion (Frohberg et. al.)
- not isolated
QUELD II forced 0.1 Hz, 0.004g
QUELD II isolated by MIM
(1.5 mm and 3 mm dia. specimens for µg
QUELD I and QUELD II experiments)
QUELD Ground-based studies
(1 mm dia. specimens)
QUELD I & QUESTS no isolation
QUELD II
(MIM not isolating)

Processing of Infra-Red Glasses in Microgravity

- Material $Nb_2Na_2B_2O_9$ (NNB)
- Processing conditions
    - Temperature 575 °C
    - Time 1 hour
    - container SiO_2
    - g-levels: isolation or 0.1 Hz square wave input with amplitude of 1 mg

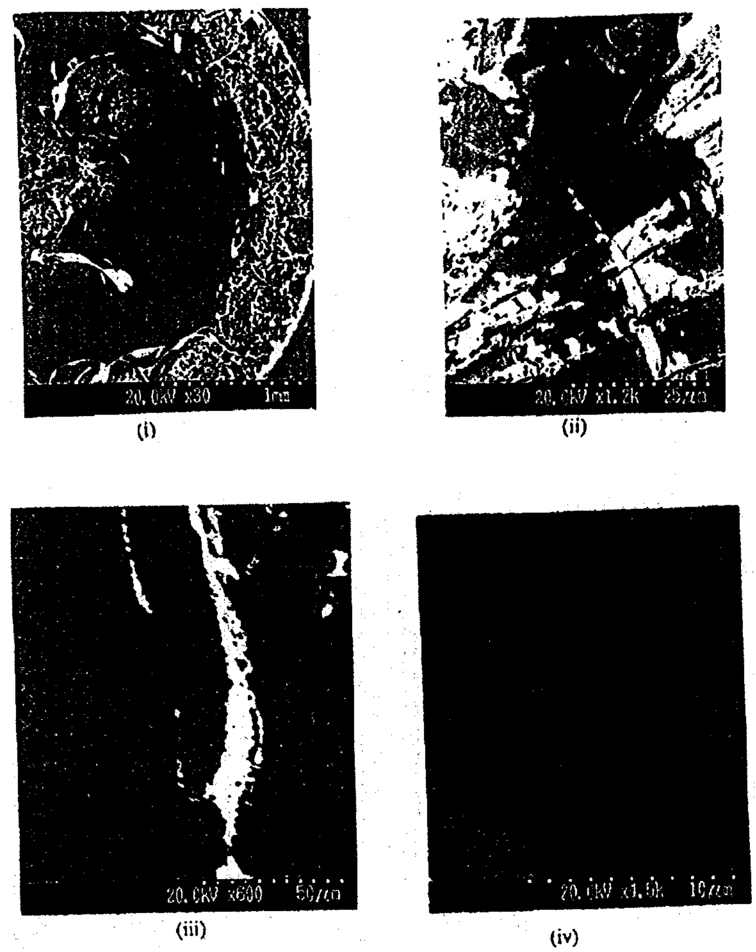


(i)

(ii)

(iii)

NNB Glass processed in microgravity at 575 K with isolation, showing (upper) a crystal phase only around the edge of specimen (enlarged center) but not in the specimen center (lower image).



NNB glass processed in microgravity having force square wave input with 1 mg amplitude at 0.1 Hz, showing mixing or streaming of crystal phase from edge to center of specimen.

Discussion

- The results of diffusion work carried out on the shuttle the Mir and the Brownian Motion experiments conducted on the shuttle show a consistent sensitivity to g-jitter.
- The sensitivity is to vibrations at frequencies above 2 Hz.
- The vibration levels that effect diffusion are generally well below the current ISS vibratory requirement for isolated racks

Conclusions

- There is agreement between the space based and ground based results
- Effects of g-jitter is seen in two and possibly three very different experiments
- All three experiments indicate that diffusion is sensitive to vibratory disturbances
- The mechanism for this sensitivity has still to be investigated

510/35 //ABS ONLY

2001017722

512571

185

MGMG #19

Paper Number: 10

Microgravity aspects of ACES: Atomic Clock Ensemble in Space

Walter E. Knabe
DySAT
Kirchlinteln, Germany

ACES has been selected and scheduled by the European Space Agency to fly on the International Space Station (ISS). ACES consists of two highly stable atomic clocks, a cold atom cesium clock and a (space) hydrogen maser, as well as suitable time and frequency transfer systems.

The innovative element of this space experiment is the laser-cooled Cs clock being developed in the French project PHARAO [Projet d'Horloge Atomique par Refroidissement d'Atomes en Orbite (A Cold Atom Clock in Space)].

. It will be utilizing the microgravity environment of ISS for achieving an appreciable improvement over presently available clock performance, particularly in terms of clock accuracy. The rationale is, that for the Cs atoms released collectively as individual laser-cooled clouds, the interaction periods with the microwave field in the clock cavity can be increased considerably (factor of ten) in the virtual weightlessness of orbital flight, over the interaction times possible in a laboratory on Earth.

Major microgravity aspects of the accommodations of ACES on ISS, including local micro-g acceleration measurement, will be indicated.

Support for the ACES/PHARAO is furnished by CNES, BNM, CNES, and ESA.

PRESENTATION MATERIAL NOT SUBMITTED AT TIME OF PRINTING

511/29 2001019724 512572 21 PS

MGMG #19

Paper Number: 11

ISS microgravity environment
Design Analysis Cycle 8

Steve DelBasso
The Boeing Company
Houston, Texas

The ISS Program has developed the eighth Design Analysis Cycle (DAC-8) of the ISS vehicle. On result of the DAC is a prediction of the microgravity acceleration environment provided by the vehicle to the payloads. The DAC-8 results will be reviewed in this presentation.

BOEING

ISS Microgravity Environment Design Analysis Cycle 8

Microgravity Measurement Group Meeting
Cleveland, Ohio
July 12, 2000

Steve Del Basso

Structural Analysis Microgravity Team
Boeing
502 Gemini Avenue
Houston, Texas
281-853-1603

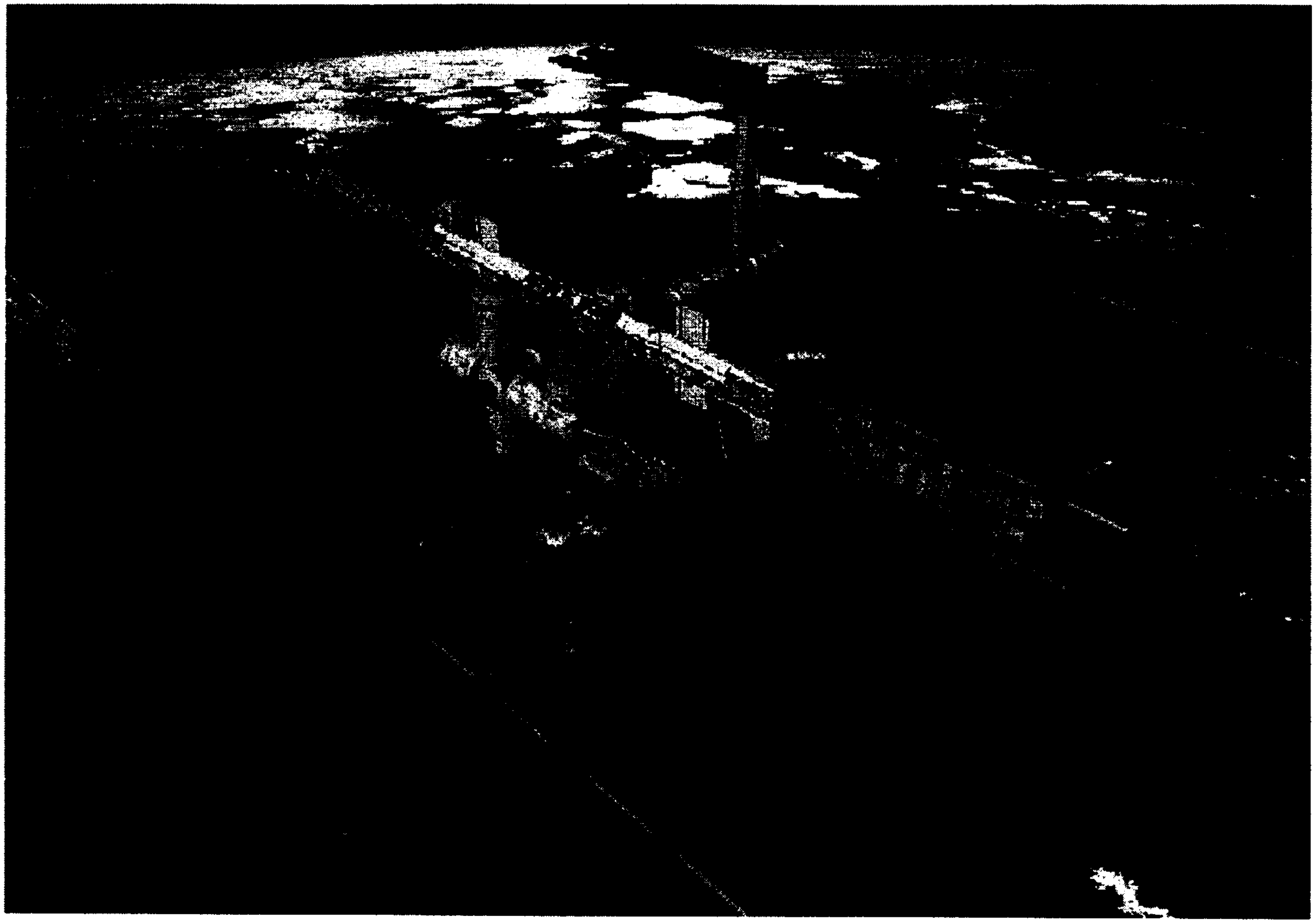
Presentation Overview

- Design Analysis Cycle 8
- Quasi-steady Accelerations
- Vibratory Accelerations
- Summary
- BACKUP:
  - Microgravity Requirements
  - Active Rack Isolation System (ARIS)

Design Analysis Cycle (DAC) 8

- DACs may be viewed as PDR/CDR level analyses or "special" case studies.
- DACs are a configuration managed process by the Vehicle Integrated Performance and Resource (VIPeR) Team:
  - Standardize input data and task description sheets (TDSs) documented in "MAPS" document to initiate DAC.
  - Results briefed to the VIPeR and documented in abstracts and final reports.
  - Abstracts published in VE-23 document as fulfillment of a contracted deliverable.
- Verification Analysis Cycles (VACs) are in process and are conducted on a stage by stage basis. VACs are similarly managed.
- Microgravity Team uses DACs for special case studies, e.g. thermal induced vibration of PV Array, and Assembly Complete total acceleration environment predictions. (DAC6 - April 1998).

Assembly Complete Configuration



DAC8 Quasi-Steady Performance

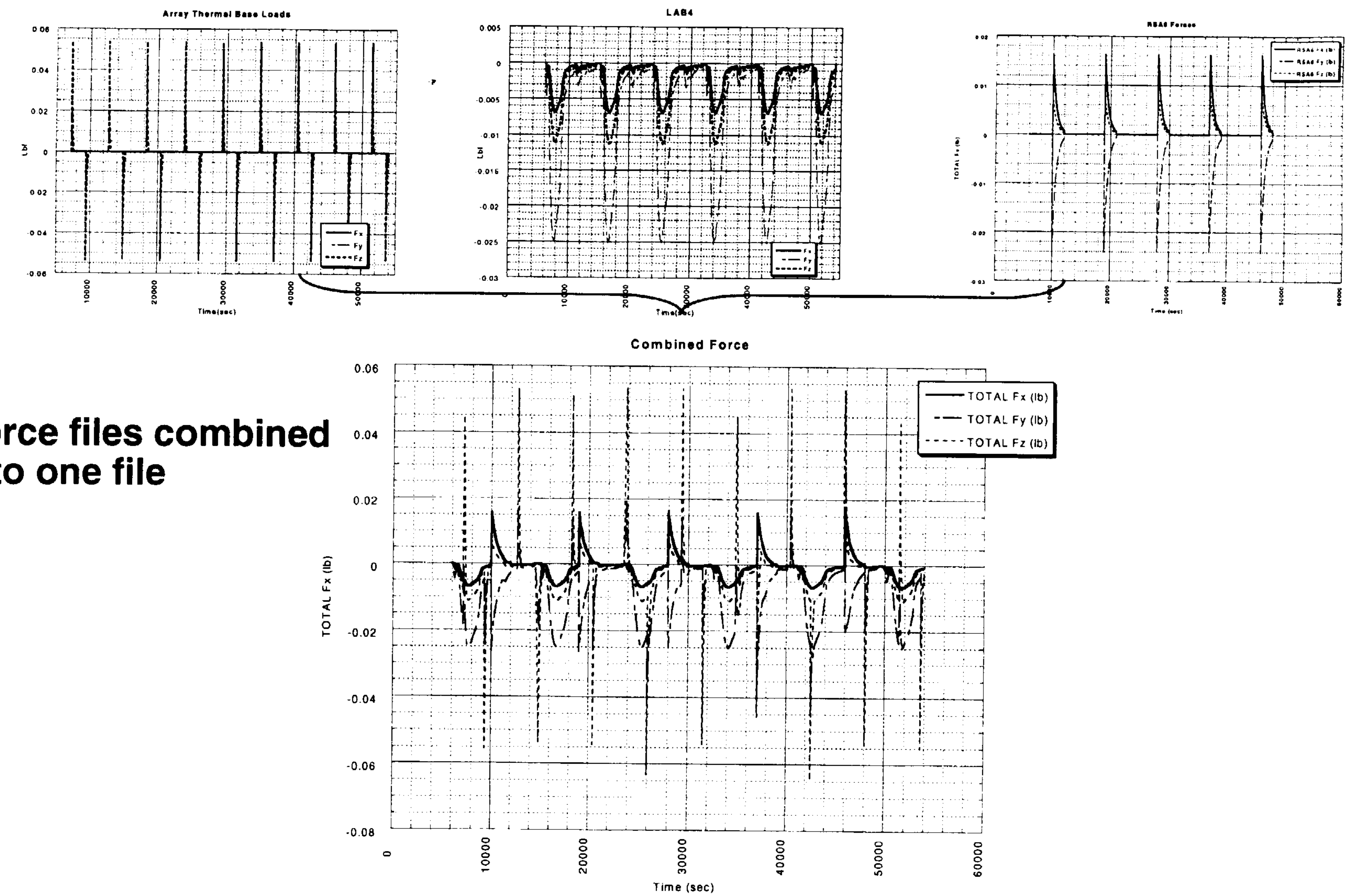
- 15 of 32 racks less than 1 μg magnitude & 0.2 μg perpendiculat component.

Location	Rack Position in ISS Frame			μG Vector		Unit Vector			Cone Angle		
	X (ft)	Y (ft)	Z (ft)	Magnitude (μG)	⊥ Component (μG)	X	Y	Z	Max angle from unit vector (deg)	⊥ Component @ max angle (μG)	Magnitude at max angle (μG)
CG	-15.34	-1.28	14.87	0.210	0.038	-0.994	-0.107	0.013	20.660	0.025	0.065
USL-C1	15.55	0.00	11.26	0.245	0.064	-0.624	-0.773	-0.119	24.100	0.054	0.122
USL-C2	12.05	0.00	11.26	0.232	0.063	-0.665	-0.722	0.191	26.258	0.050	0.101
USL-C3	8.55	0.00	11.26	0.230	0.070	-0.635	-0.584	0.506	26.070	0.051	0.104
USL-C4	5.05	0.00	11.26	0.243	0.078	-0.546	-0.406	0.733	23.624	0.056	0.129
USL-C5	1.55	0.00	11.26	0.266	0.084	-0.446	-0.247	0.860	20.229	0.062	0.168
USL-S1	15.55	4.84	16.11	0.689	0.087	-0.321	0.068	-0.945	7.346	0.087	0.672
USL-S2	12.05	4.84	16.11	0.645	0.086	-0.340	0.108	-0.934	7.765	0.086	0.628
USL-S3	8.55	4.84	16.11	0.602	0.084	-0.362	0.154	-0.919	8.219	0.084	0.584
USL-S4	5.05	4.84	16.11	0.560	0.083	-0.386	0.207	-0.899	8.793	0.076	0.488
USL-P1	15.55	-4.84	16.11	0.722	0.088	-0.217	-0.488	-0.845	7.082	0.088	0.707
USL-P2	12.05	-4.84	16.11	0.671	0.087	-0.230	-0.497	-0.837	7.551	0.087	0.656
USL-P4	5.00	-4.84	16.11	0.570	0.085	-0.264	-0.519	-0.813	8.725	0.084	0.546
JPM1-A1	29.66	-10.82	15.92	1.035	0.091	-0.126	-0.652	-0.748	5.190	0.091	1.006
JPM2-F1	40.00	-10.82	15.92	1.193	0.093	-0.118	-0.617	-0.778	4.618	0.093	1.156
JPM3-A2	29.66	-14.32	15.92	1.121	0.092	-0.097	-0.726	-0.680	4.810	0.092	1.089
JPM4-F2	40.00	-14.32	15.92	1.274	0.094	-0.094	-0.688	-0.720	4.339	0.094	1.234
JPM5-A3	29.66	-17.82	15.92	1.217	0.092	-0.072	-0.783	-0.617	4.450	0.092	1.182
JPM6-F3	40.00	-17.82	15.92	1.364	0.094	-0.072	-0.744	-0.664	4.068	0.094	1.321
JPM7-A4	29.66	-21.32	15.92	1.320	0.093	-0.050	-0.827	-0.561	4.122	0.093	1.283
JPM8-A5	29.66	-24.82	15.92	1.429	0.093	-0.032	-0.860	-0.510	3.831	0.093	1.392
JPM9-F5	40.00	-24.82	15.92	1.566	0.095	-0.036	-0.825	-0.564	3.585	0.095	1.520
JPM10-F6	40.00	-28.32	15.92	1.675	0.096	-0.021	-0.854	-0.521	3.384	0.096	1.627
APM-CLG1	34.84	14.39	10.74	0.517	0.089	-0.435	0.684	-0.586	9.998	0.089	0.505
APM-CLG2	34.84	18.33	10.74	0.640	0.093	-0.379	0.794	-0.475	8.422	0.093	0.629
APM-FWD1	40.00	14.39	15.91	1.078	0.094	-0.272	0.266	-0.925	5.027	0.094	1.067
APM-FWD2	40.00	18.33	15.91	1.146	0.095	-0.277	0.390	-0.878	4.781	0.095	1.135
APM-FWD3	40.00	22.26	15.91	1.229	0.096	-0.277	0.493	-0.825	4.521	0.096	1.219
APM-FWD4	40.00	26.19	15.91	1.326	0.098	-0.274	0.576	-0.771	4.267	0.098	1.316
APM-AFT1	29.67	14.39	15.91	0.963	0.092	-0.297	0.366	-0.882	5.528	0.092	0.951
APM-AFT2	29.67	18.33	15.91	1.045	0.094	-0.295	0.491	-0.820	5.173	0.094	1.033
APM-AFT3	29.67	22.26	15.91	1.142	0.095	-0.290	0.587	-0.756	4.824	0.095	1.131
APM-AFT4	29.67	26.19	15.91	1.251	0.098	-0.282	0.661	-0.695	4.504	0.098	1.242
CAM-MID	36.08	0.00	4.17	0.608	0.091	-0.045	-0.410	0.911	8.877	0.091	0.581
CAM-TOP	36.08	0.00	0.00	1.077	0.092	0.033	-0.216	0.976	5.019	0.092	1.042

DAC8 Quasi-steady Individual Disturbance Inputs

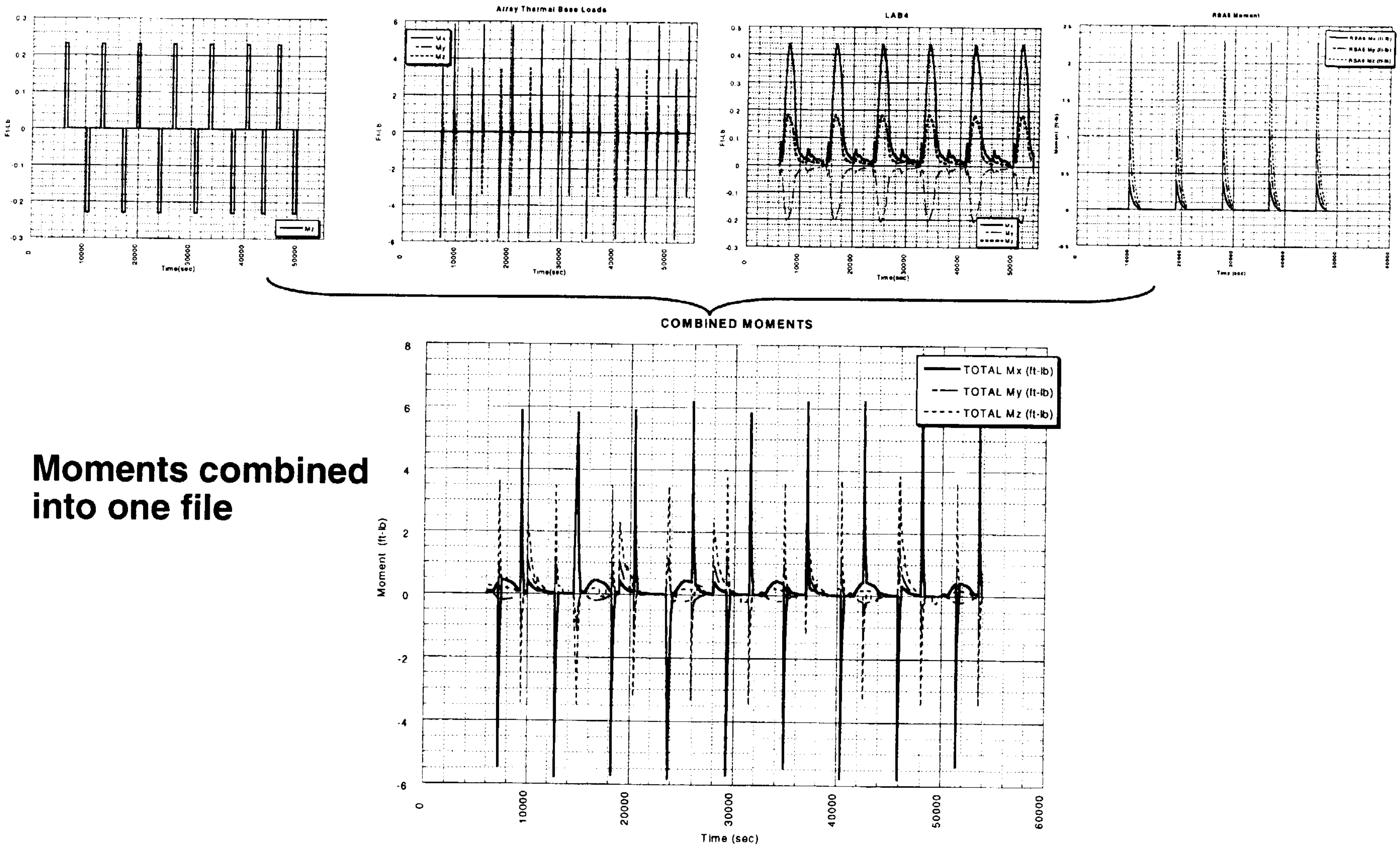
- **Centrifuge startup and shut down**
  - Spin-up for 120 sec to 236 deg/s, spin for 6.4 hours, spin-down for 120 sec.
  - Starts at 17000 sec
- **TRRJ slew at low betas**
  - TRRJ 0 beta slew rates - TRRJ Torque Power Spectral Density has 87.7% of its power below .01 Hz.
  - Not Applicable
- **Solar Thermal base loads**
  - Exponential decay for 210 seconds ever 2160 seconds (night), 3360 (day), forces combined for eight arrays
  - Lighting dependent , continuous
- **LAB4 Vent**
  - Force profile, duration of 8700 seconds
  - Starts at 6000 seconds
- **RSA6 Vent**
  - Exponential decay of 600 seconds ever 9000 seconds
  - Starts at 10000 seconds
- **Treadmill Gyro Start-up**
  - +.23 ft-lbs. for 10minutes, 0 ft-lbs. for 60 minutes, -.23 ft-lbs. for 10 minutes, repeated every 30 minutes.
  - Starts at 6000 seconds

DAC8 Quasi-steady Individual Disturbance Inputs



Force files combined into one file

DAC8 Quasi-steady Individual Disturbance Inputs



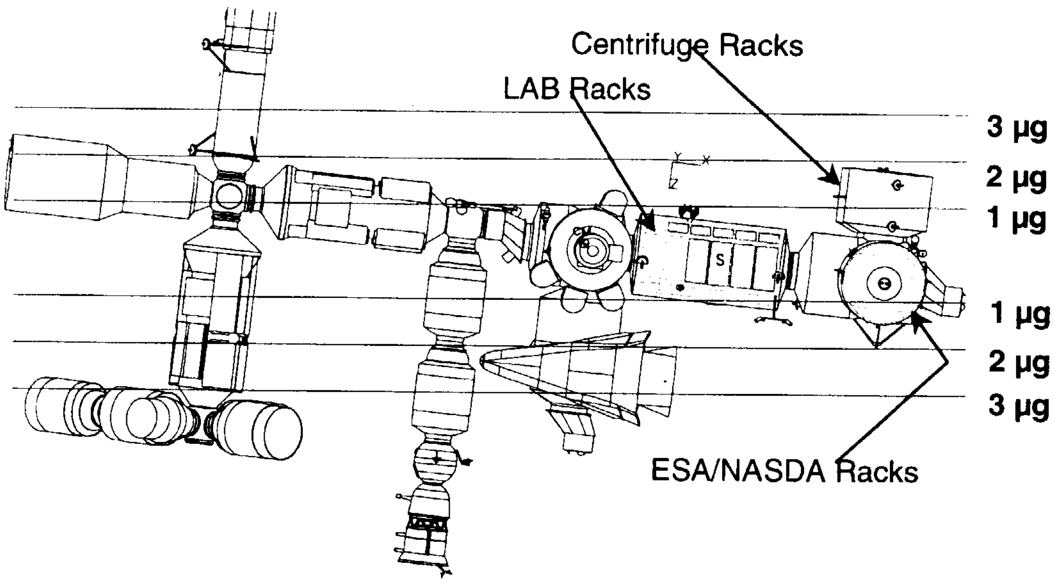
Moments combined into one file

DAC8 Quasi-Steady Performance With Individual Disturbances Delta Comparison

- 14 versus 15 of 32 racks under 1 μg magnitude and .2 μg perpendicular component (APM AFT1 to 1.068 & 0.22)

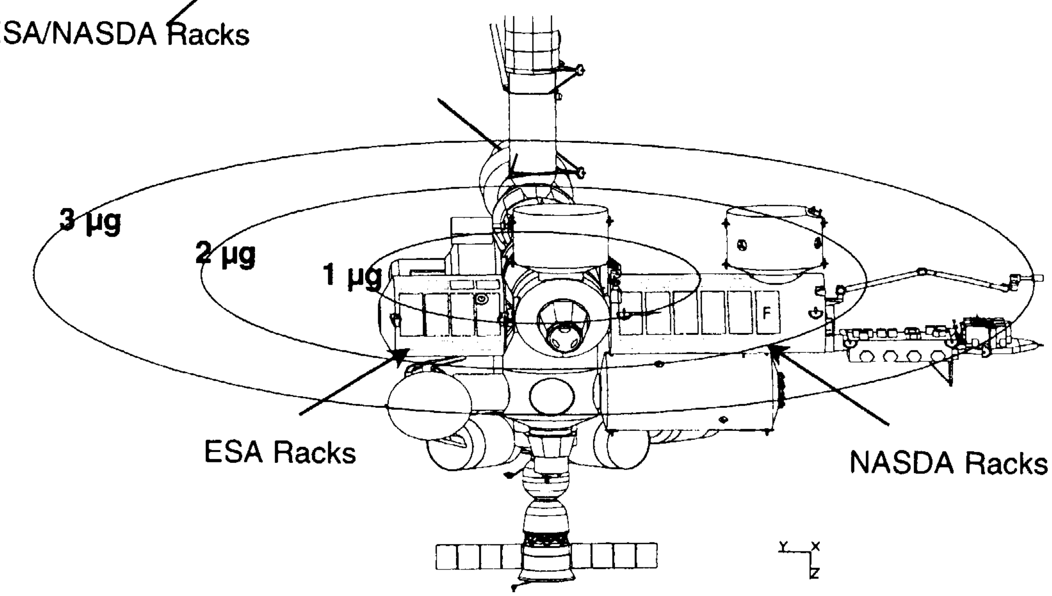
Location	Magnitude Disturbance (□G)	Magnitude Nominal (□G)	Magnitude Delta Dist-Nom (□G)	Mag % Difference	□ Component Disturbance (□G)	□ Component Nominal (□G)	□ Component Delta Dist-Nom (□G)	□ Component % Difference
CG	0.211	0.210	0.001	0%	0.080	0.046	0.203	74%
USL-C1	0.293	0.245	0.048	20%	0.158	0.064	0.094	147%
USL-C2	0.269	0.232	0.037	16%	0.150	0.063	0.087	138%
USL-C3	0.258	0.230	0.028	12%	0.140	0.070	0.070	100%
USL-C4	0.259	0.243	0.016	7%	0.128	0.078	0.050	64%
USL-C5	0.293	0.266	0.027	10%	0.116	0.084	0.032	38%
USL-S1	0.711	0.689	0.022	3%	0.170	0.087	0.083	95%
USL-S2	0.668	0.645	0.023	4%	0.156	0.086	0.070	81%
USL-S3	0.625	0.602	0.023	4%	0.142	0.084	0.058	69%
USL-S4	0.584	0.560	0.024	4%	0.128	0.083	0.045	54%
USL-P1	0.791	0.722	0.069	10%	0.139	0.088	0.051	58%
USL-P2	0.735	0.671	0.064	10%	0.127	0.087	0.040	46%
USL-P4	0.623	0.570	0.053	9%	0.105	0.085	0.020	24%
JPM1-A1	1.132	1.035	0.097	9%	0.150	0.091	0.059	65%
JPM2-F1	1.293	1.193	0.100	8%	0.188	0.093	0.095	102%
JPM3-A2	1.225	1.121	0.104	9%	0.153	0.092	0.061	66%
JPM4-F2	1.383	1.274	0.109	9%	0.172	0.094	0.078	83%
JPM5-A3	1.327	1.217	0.110	9%	0.157	0.092	0.065	71%
JPM6-F3	1.480	1.364	0.116	9%	0.174	0.094	0.080	85%
JPM7-A4	1.435	1.320	0.115	9%	0.162	0.093	0.069	74%
JPM8-A5	1.547	1.429	0.118	8%	0.168	0.093	0.075	81%
JPM9-F5	1.691	1.566	0.125	8%	0.183	0.095	0.088	93%
JPM10-F6	1.804	1.675	0.129	8%	0.189	0.096	0.093	97%
APM-CLG1	0.710	0.517	0.193	37%	0.151	0.089	0.062	70%
APM-CLG2	0.856	0.640	0.216	34%	0.133	0.093	0.040	43%
APM-FWD1	1.184	1.078	0.106	10%	0.268	0.094	0.174	185%
APM-FWD2	1.283	1.146	0.137	12%	0.259	0.095	0.164	173%
APM-FWD3	1.393	1.229	0.164	13%	0.249	0.096	0.153	159%
APM-FWD4	1.513	1.326	0.187	14%	0.242	0.098	0.144	147%
APM-AFT1	1.068	0.963	0.105	11%	0.219	0.092	0.127	138%
APM-AFT2	1.176	1.045	0.131	13%	0.211	0.094	0.117	124%
APM-AFT3	1.296	1.142	0.154	13%	0.206	0.095	0.111	117%
APM-AFT4	1.423	1.251	0.172	14%	0.206	0.098	0.108	110%
CAM-MID	0.650	0.608	0.042	7%	0.238	0.091	0.147	162%
CAM-TOP	1.100	1.077	0.023	2%	0.252	0.092	0.160	174%

DAC8 Quasi-Steady Performance

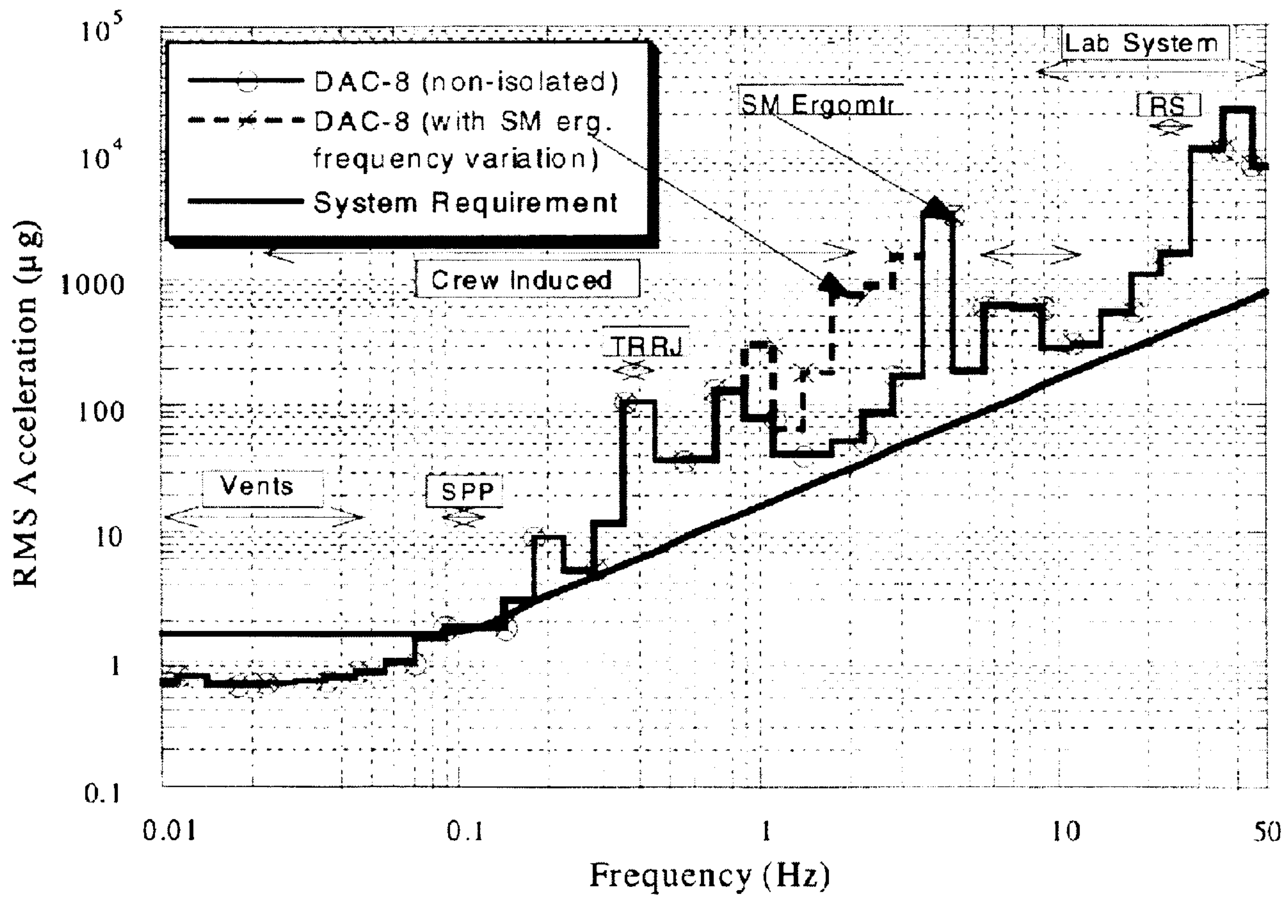


Quasi-steady Performance:
- 15 of 32 ISPRs < 1.0
- 16 of 32 ISPRs < 1.2
- All satisfy stability criteria

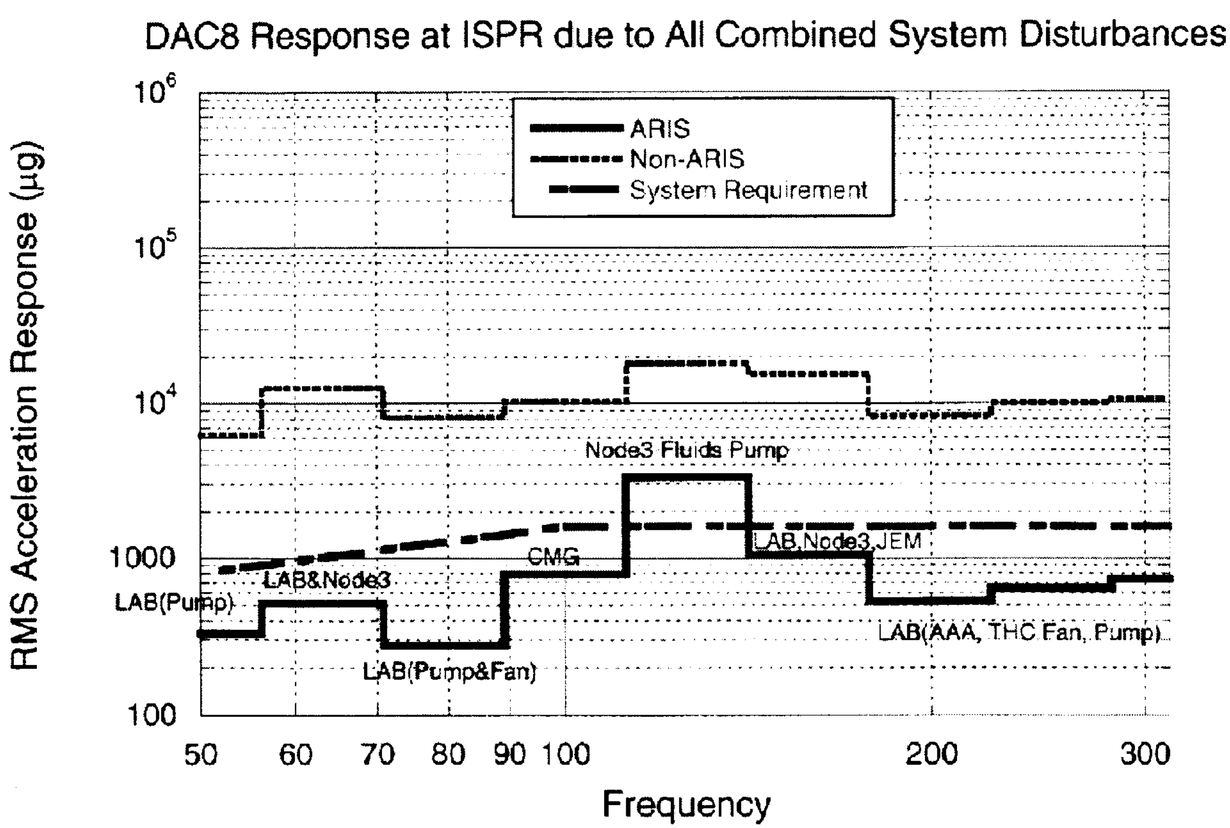
Flight Attitude:
- Pitch -6.97 degrees
- Yaw -8.07 degrees
- Roll 1.16 degrees



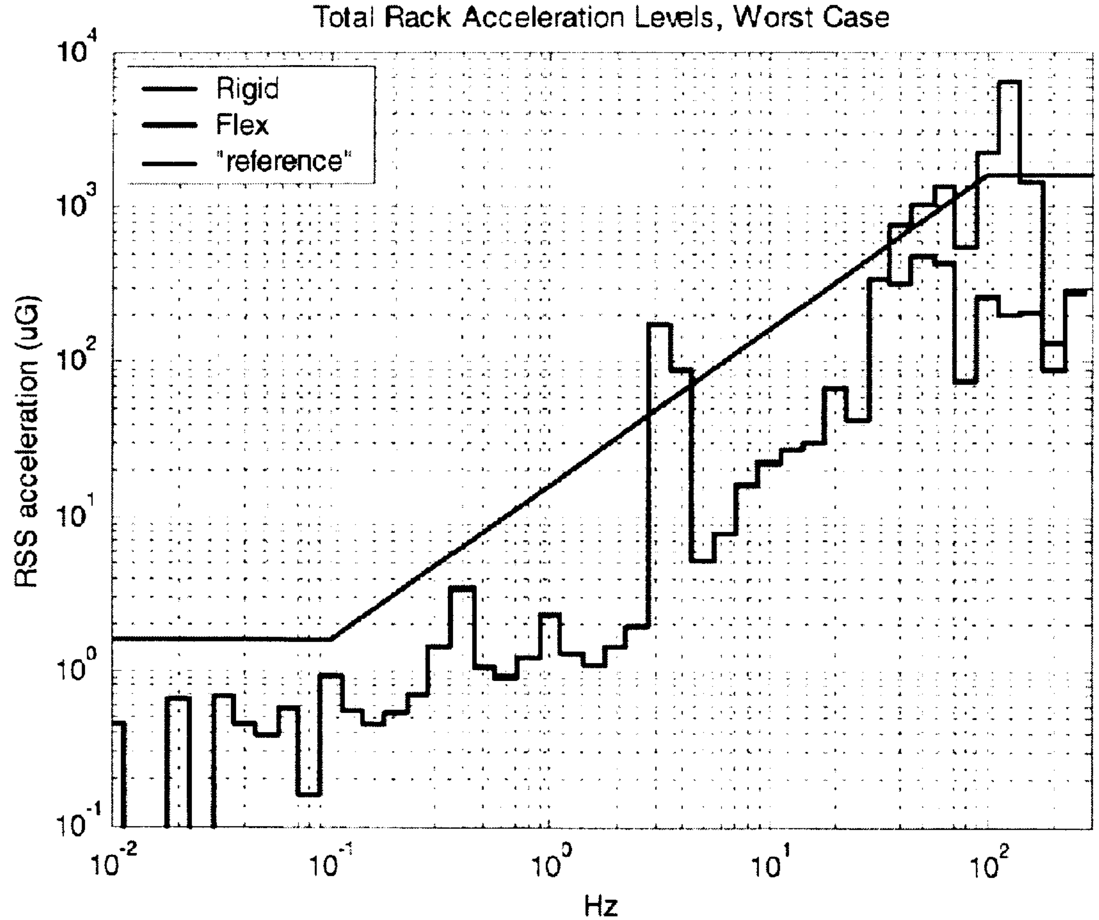
DAC8 Non-Isolated Performance
Structural Dynamic Frequency Range



DAC8 Performance
Vibroacoustic Frequency Range



Total Isolated Rack Acceleration Levels (ARIS Verification Conditions)



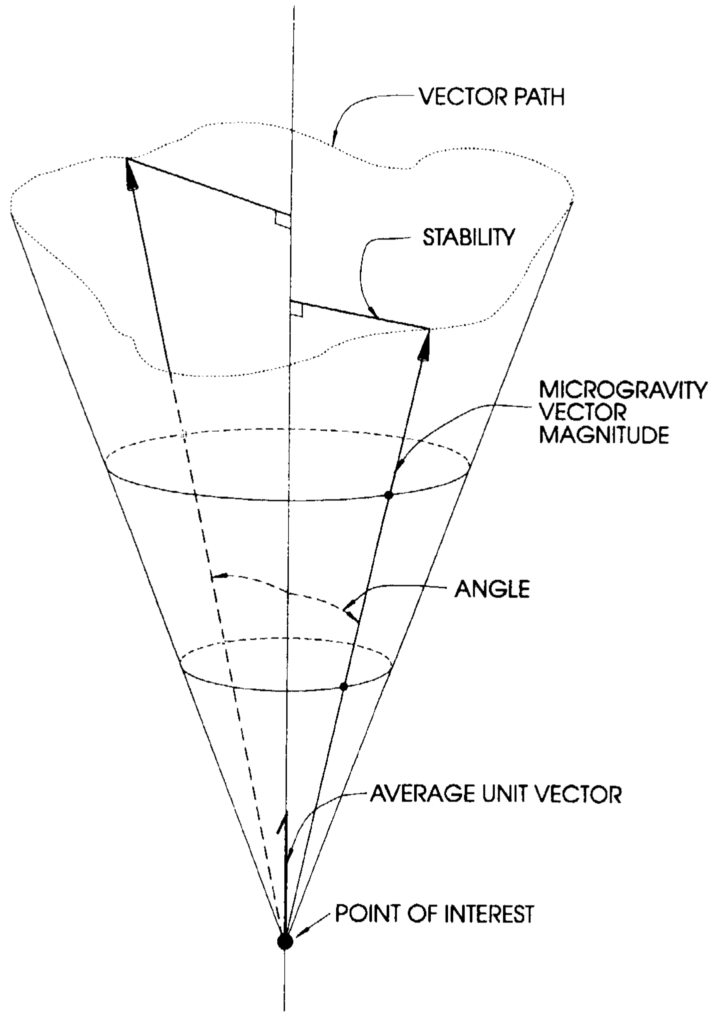
Summary

- Recent Lab Test correlation effort supports position that analytical predictions maintain conservatism consistent with Assembly Complete simulation model uncertainty & lack of full disturbance test program/knowledge (e.g. 0.25% modal damping factor).
- Use early on-orbit measurement data to establish confidence in analytical models and support operations and anomaly resolution.
- Key threats & planned/recommended countermeasures:
  - ARIS isolation performance - Approved “shake down” experiment on flight 6A - “ARIS ICE”.
  - Service Module air conditioner compressor non-compliance - Approved ground test and on-orbit installation of vibration mounts and extended fluid flex lines.
  - Service Module ergometer non-compliance with verified ARIS performance. - Pursue early measurements to confirm predictions and resolve if necessary.
  - Potentially significant disturbances still not well characterized. (e.g. flight crew systems equipment) - Maintain vigilance.
  - Potential of payload disturbances & structural dynamics, and verification process. - Recommend additional efforts to close gap.

BACKUP MATERIAL:

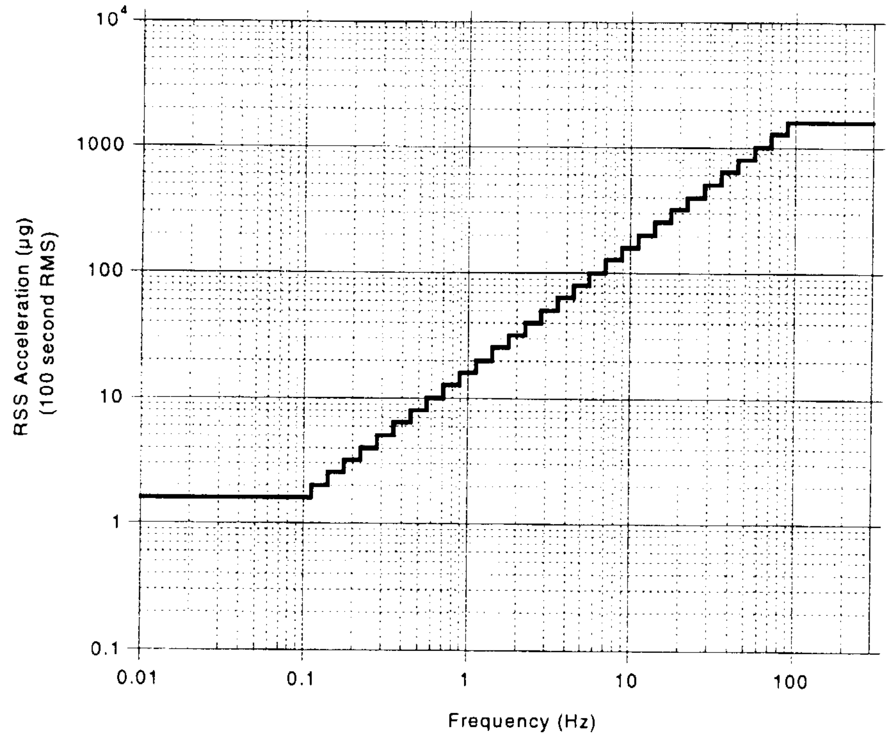
- Microgravity Requirements
- Active Rack Isolation System

Quasi-Steady Microgravity Requirements



- **Duration**
  - **Periods: >/= 30 days**
  - **Yearly Total: >/= 180 days / year**
- **Location - at ISPR center**
- **Magnitude - 1.0 μg (0 </= f </= 0.01 Hz.)**
- **Stability - 0.2 μg perpendicular component to orbital average QS acceleration vector**

Vibratory Microgravity Requirements

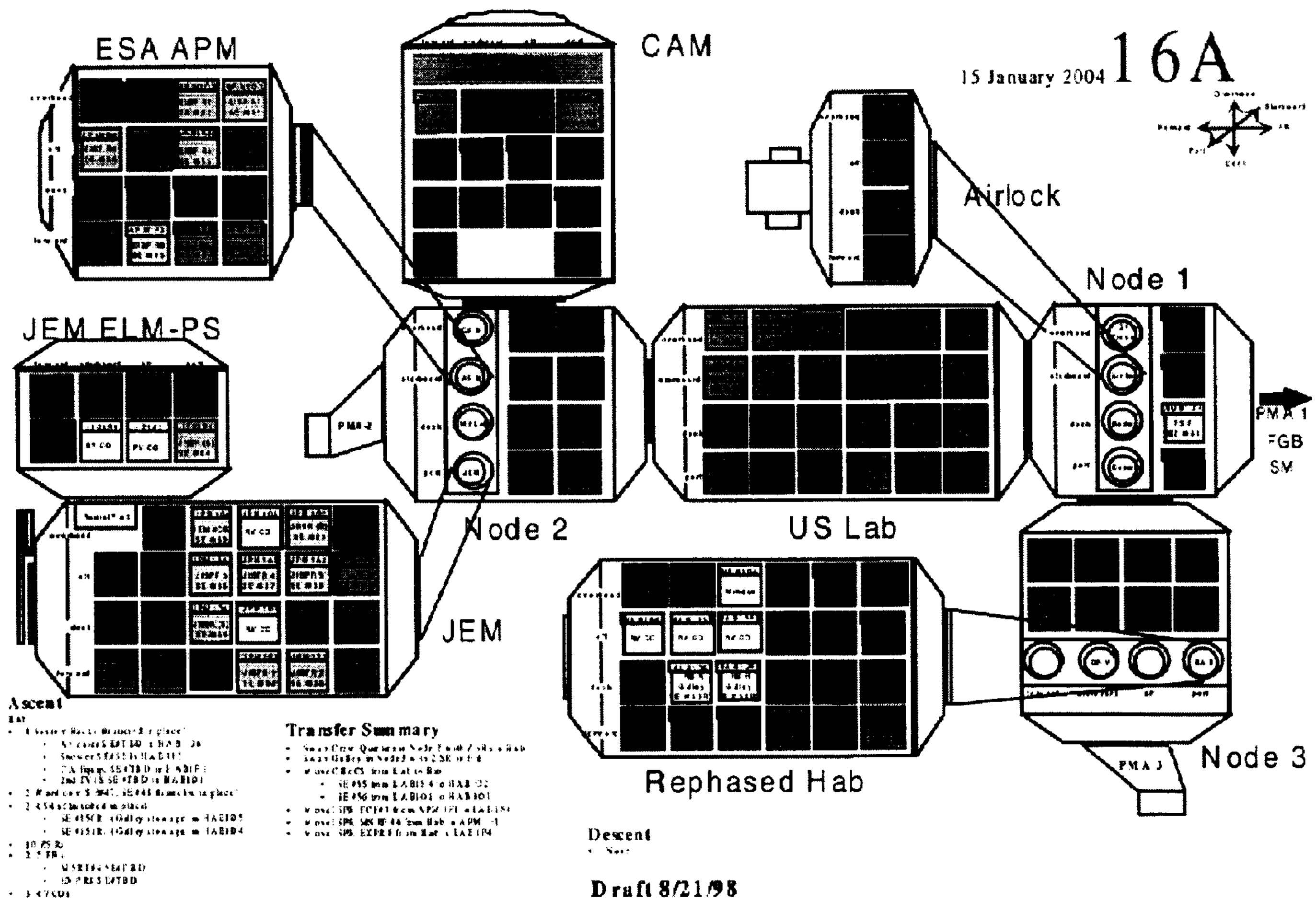


- **Duration - same as quasi-steady**
- **Location - at module/ISPR interface**
- **Combined Vibratory - per figure (0.01 </= f </=300.0 Hz.)**
  - **100 second root mean square average**
  - **Per one-third octave band**
- **Individual Transient**
  - **1000 µg peak per axis**
  - **10 µg*s integrated over any 10 s interval per axis**

18

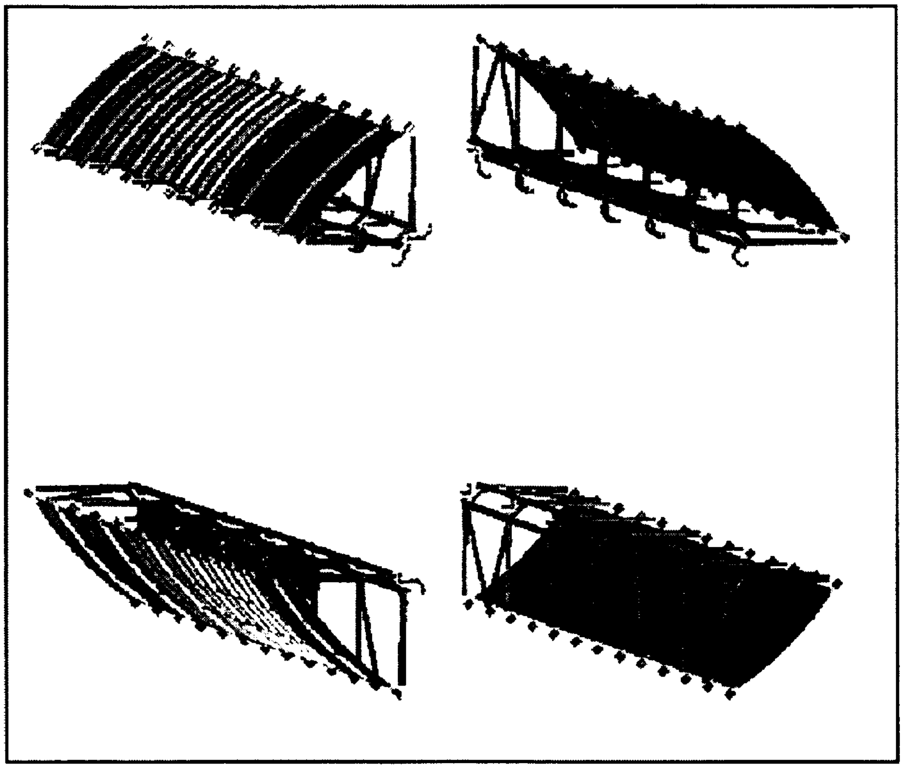
Requirement Applicability

■ ISPR Layout



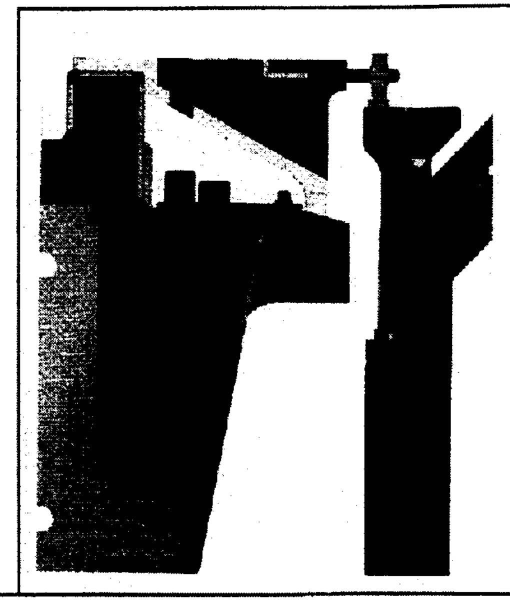
Requirement Applicability

- Rack to Module Interface

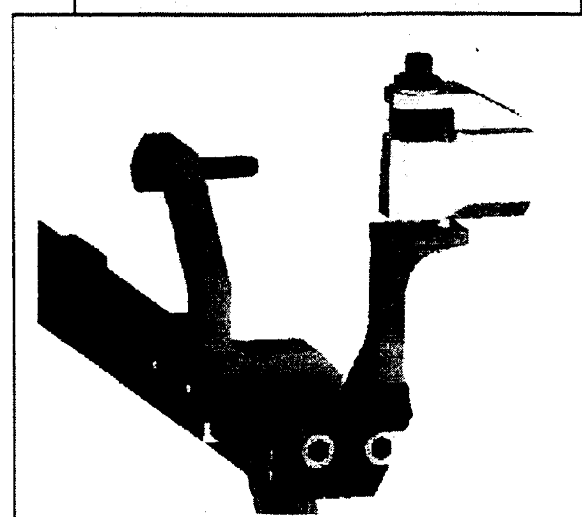


Lab Standoffs

Upper Rack Attach

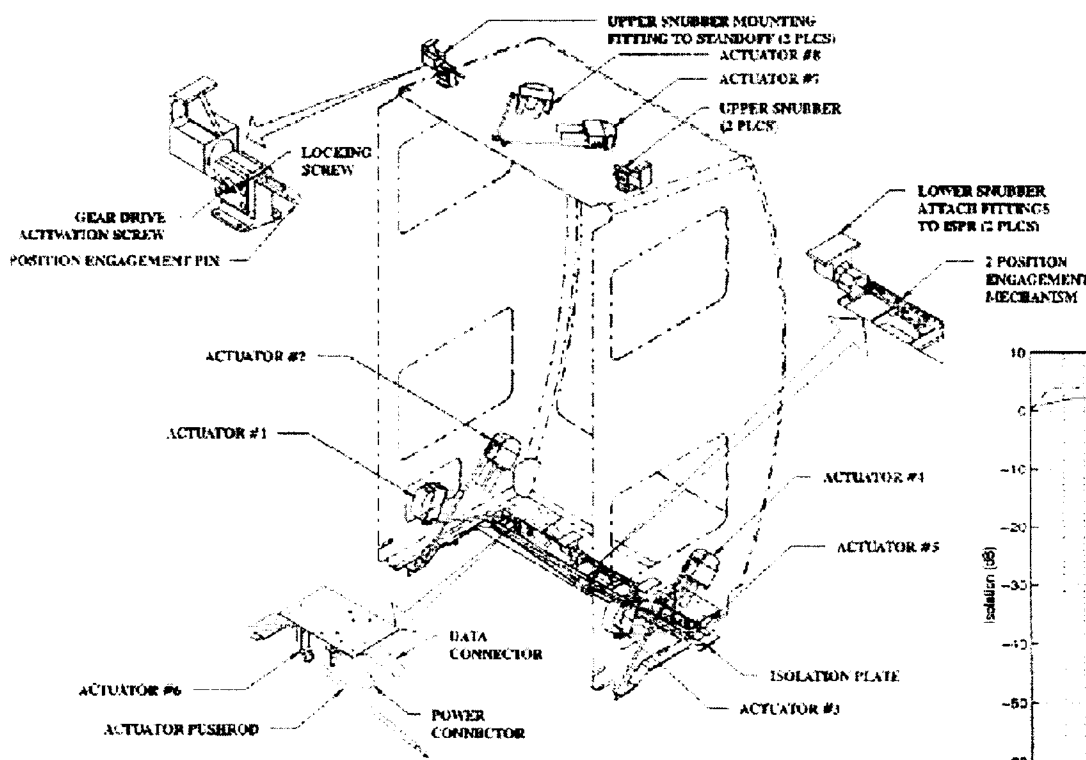


Lower Rack Attach

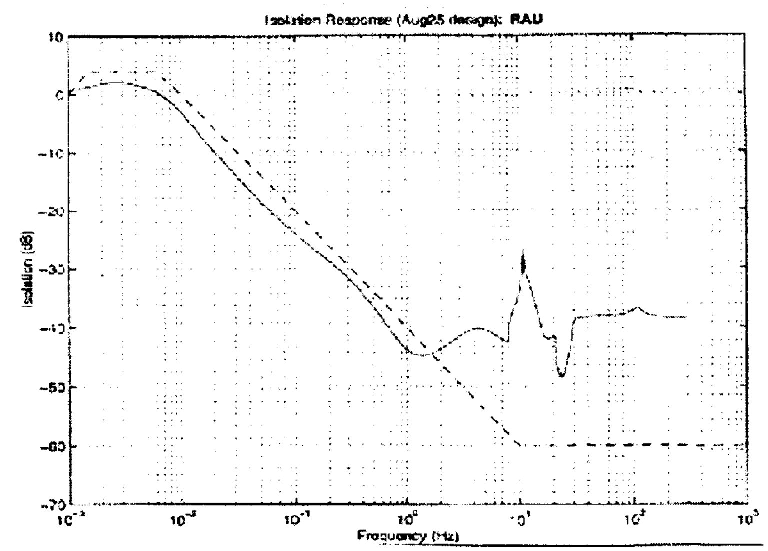


Rack Isolation - ARIS

ACTIVE RACK ISOLATION SYSTEM
CONTROL ASSEMBLY



Isolation Performance Prediction



5/2/29 2001019725 512573 35 pg

MGMG #19

Paper Number: 12

Microgravity disturbance database – DAC 8

Otto Crenwelge
Dynacs Information & Applied Technology
Houston, Texas

A microgravity disturbance forcing function database is maintained by the Microgravity Team. The database consists of all Boeing and International Partner estimates of their respective disturbances as well as estimates for GFE hardware and crew intravehicular activities. A continuing assessment is made of the completeness of capture of the disturber equipment list. A continuing assessment is also made of the adequacy of all mechanical, acoustical, and flow forcing functions to help pinpoint weaknesses that need to be addressed. Thermal forcing functions are treated separately. The effects of preventative maintenance procedures are determined, and, if necessary, their disturbance descriptions are analyzed, developed, and incorporated into the database.

This presentation discusses the DAC8 Microgravity Disturbance Database. An update of the current database is available. The database contains a listing of all disturber equipment and their disturbance descriptions. Assessments of the adequacy of disturbance descriptions and the completeness of capture of disturber equipment were performed for all elements of the assembly complete ISS and presented at the DAC8 VIPeR meeting, June 1, 2000. These are summarized in the presentation, along with comments and issues re the element disturbance databases.

Microgravity Disturbances

Microgravity Disturbance Database - DAC8

TDS D8.3-1

Otto Crenwelge

19th Microgravity Measurements Group Meeting

11-13 July 2000

Dynacs Information & Applied Technology

BOEING

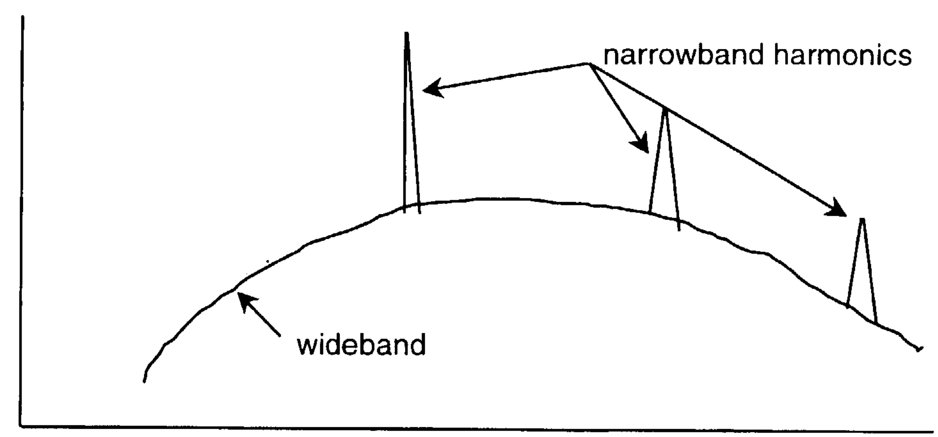
Task Description

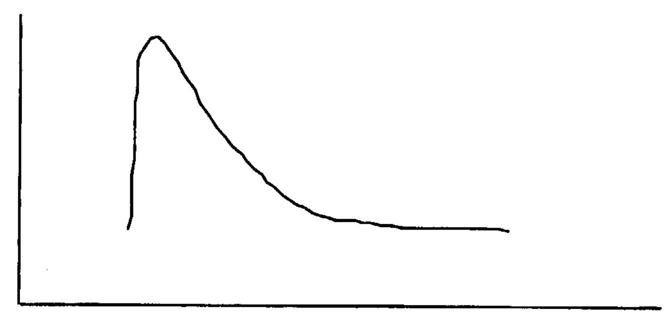
- Update Disturbance Database
- Assess Capture of Disturber Equipment
- Assess Adequacy of Disturbance Descriptions
- Assess Effects of Preventive Maintenance Procedures
- Tools
  - Flight Manifests
  - VMDB
  - MGAIT DAC Disturbance Database
  - Element Integrator Disturbance Databases
  - Element Integrator Verification Reports
  - Compare disturbance descriptions with test, similarity, and analytical data
  - R&M S&MA Allocations, Assessments, and Analyses Reports

Disturber Definitions

- A Microgravity Critical Item (MGCI) disturber is one whose induced accelerations are >/= 50% of the element level requirement. When there are multiples of the item in simultaneous operation, the criteria applies to the aggregate rather than the individual items.
- As used in the accuracy assessment, "significant" disturbers are those that account for >/= 20% of the total mean square acceleration in any 1/3 octave band.
- As used in the accuracy assessment, "major" disturbers are those whose induced accelerations exceed microgravity requirements in any 1/3 octave band without ARIS attenuation.

Disturbance Characteristics





Basis Rating Scheme

Rating	Basis of Disturbance Measurement/Analysis Approach
– 10	Measured data on identical equipment
– 9	
– 8	Measured data on similar equipment
– 7	
– 6	CDR level analysis
– 5	
– 4	PDR analysis
– 3	
– 2	Estimate based on preliminary equipment characteristics
– 1	Early estimate based on engineering judgement
– 0	No information
–	Not applicable

Characteristics Weighting Scheme

(for disturbances external to ISPR)

Weighting	Disturbance Source Characteristics
N/A	Quasi-steady
	Vibratory
	Mechanical
8	Narrowband fundamental
4	Narrowband harmonic
4	Transient
2	Wideband
	Acoustical
4	Narrowband fundamental
2	Narrowband harmonic
2	Transient
1	Wideband
x	Other engineering judgement factors

Adequacy Rating

For each disturber type:

$$\text{Adequacy Rating} = \frac{\Sigma\,(\text{Rating x Weighting})}{\Sigma\,(\text{Weighting})}$$

Adequacy Requirements

- The expected adequacy rating for verification of MGCI equipment is 7 or higher
- The expected adequacy rating for verification of non-MGCI equipment is 6 (CDR)

Maintenance

- Task Description
  - Consider all scheduled (service, inspect, repair, replace) items which must be performed in 90 day increments or less
  - Assess the effects of procedures on the microgravity environment
  - If necessary, analyze and develop force and moment descriptions for for procedures and incorporate in Microgravity Forcing Function Database

Summary

ELEMENT	DISTURBANCE ADEQUACY RATING	DISTURBER EQUIPMENT CAPTURE	MAINTENANCE ACTIVITIES WITHIN 90 DAYS	COMMENTS	ISSUES & RECOMMENDATION
FGB	5.6 / 10	Complete.	Clean and inspect activities only.	Due to shortage of wideband noise and vib data, verified using US generic data.	None. On-orbit.
NODE 1	9 / 10	Complete.	Clean and inspect activities only.	Verified using fan force and sound power from 8/98 N1 tests at KSC.	None. On-orbit.
PMA 1, 2, 3	NA	No micro-g disturbers.	None expected.	Passive module.	None. PMA 1 & 2 are on-orbit.
SM	6.3 / 10	Complete.	Have requested, but RSCE has not provided.	RSCE supplied low f ergometer test data and SA & HGA analytical data and high f vib test data at SM/FGB interface.	Expander disturbances not supplied. These are highly dependent upon operation, and should be measured on-orbit. No maintenance info provided.

Summary

ELEMENT	DISTURBANCE ADEQUACY RATING	DISTURBER EQUIPMENT CAPTURE	MAINTENANCE ACTIVITIES WITHIN 90 DAYS	COMMENTS	ISSUES & RECOMMENDATION
Treadmill with Vibration Isolation and Stabilization (TVIS)	9/10	Complete.	Have requested, but have not received.	Analysis using force test data shows compliance during normal activities. LMSC rationale indicates compliance for gyros and transient startup and entry.	Need scheduled maintenance data. Recommend on-orbit measurements to assure meeting AC requirements during transients.
Z1	8 / 10	Complete.	None.	Verified with CMG test data and KuBA simulation data.	None.
Soyuz	NA	NA	None expected.	Passive during micro-g mode.	None.
P6/S6 & P4/S4	5.9 / 10 for flow, TCS pumps, and BGA motors and 7/10 for thermally induced stick-slip (TISS), modal deflection (TIMD), and slowly varying deflection (TISVD).	Complete.	None.	BGA motors, TCS pumps, and flow provide only low level excitations. BHOU analyses show that TISS is MGCI. TIMD are negligible. BHOU is analyzing non-linear TIMD.	None.

Summary

ELEMENT	DISTURBANCE ADEQUACY RATING	DISTURBER EQUIPMENT CAPTURE	MAINTENANCE ACTIVITIES WITHIN 90 DAYS	COMMENTS	ISSUES & RECOMMENDATION
US LAB	6 / 10	Complete.	Clean, inspect, dry out, and service activities only.	CO_2 vent, AAA fan, TCS pump, THC fan, and MCA pump are MGCI. TCS, THC, and MCA adequacy ratings fall short of required 7/10.	None. Adequacy shortfall should be contained by conservatism in analyses as shown by correlation ratios from the KSC USL Micro-g Tests (12/99 & 2/00) with all equipment operating. For equipment common to other elements, recommend extracting forcing functions from KSC test data for verification and SE.
ISPR	4 / 10	Disturber equipment lists have not been provided.	Maintenance lists have not been provided.	Uses BHV test and analytical data for selected fans, pumps, etc.	Better payload equipment and disturbance definitions are needed.
AIRLOCK	6 / 10	Complete.	Clean and inspect activities only	None.	None.

Summary

ELEMENT	DISTURBANCE ADEQUACY RATING	DISTURBER EQUIPMENT CAPTURE	MAINTENANCE ACTIVITIES WITHIN 90 DAYS	COMMENTS	ISSUES & RECOMMENDATION
DC 1, 2	No disturbances provided.	Disturber equipment list not provided.	Maintenance lists have not been provided.	None.	Need disturbance, equipment, and maintenance data.
S0	NA	No micro-g disturbers.	None.	Passive element.	None.
S1/P1	7 / 10	Needs manifest check.	None.	TRRJ is a MGCI. TRRJ test disturbance functions have been provided.	None.
SPP	4 / 10	Needs manifest check.	Maintenance lists have not been provided.	None.	Need improved disturbance and maintenance data.
S3/P3	8 / 10	Needs manifest check.	None.	SARJ test disturbance functions are currently being developed.	None.

Summary

ELEMENT	DISTURBANCE ADEQUACY RATING	DISTURBER EQUIPMENT CAPTURE	MAINTENANCE ACTIVITIES WITHIN 90 DAYS	COMMENTS	ISSUES & RECOMMENDATION
P5/S5	NA	No micro-g disturbers.	None.	Passive element.	None.
UDM	No disturbances provided.	Disturber equipment list not provided.	Maintenance lists have not been provided.	None.	Need disturbance, equipment, and maintenance data.
NODE2	6/10	Needs manifest check.	Maintenance lists have not been provided.	Using USL analytical disturbance descriptions.	Need maintenance data.
PROPULSION MODULE	No disturbances provided.	Disturber equipment list not provided.	Maintenance lists have not been provided.	None.	Need disturbance, equipment, and maintenance data.
ELM PS	4 / 10	Needs manifest check.	Maintenance lists have not been provided.	None.	Need improved disturbance and maintenance data.

Summary

ELEMENT	DISTURBANCE ADEQUACY RATING	DISTURBER EQUIPMENT CAPTURE	MAINTENANCE ACTIVITIES WITHIN 90 DAYS	COMMENTS	ISSUES & RECOMMENDATION
JEM PM	4 / 10	Needs manifest check.	Maintenance lists have not been provided.	None.	Need improved disturbance and maintenance data.
JEM EF	4 / 10	Needs manifest check.	Maintenance lists have not been provided.	None.	Need improved disturbance and maintenance data.
ELM ES	4 / 10	Needs manifest check.	Maintenance lists have not been provided.	None.	Need improved disturbance and maintenance data.
DSM	No disturbances provided.	Disturber equipment list not provided.	Maintenance lists have not been provided.	None.	Need disturbance, equipment, and maintenance data.
Cupola	No disturbances provided.	Disturber equipment list provided, but window cover mechanism not included.	Maintenance lists have not been provided.	None.	Need disturbance, equipment, and maintenance data.

Summary

ELEMENT	DISTURBANCE ADEQUACY RATING	DISTURBER EQUIPMENT CAPTURE	MAINTENANCE ACTIVITIES WITHIN 90 DAYS	COMMENTS	ISSUES & RECOMMENDATION
NODE 3	6/10	Needs manifest check.	Maintenance lists have not been provided.	Using USL and Hab analytical disturbance descriptions.	Need maintenance data.
APM (COF)	9 / 10	Needs manifest check.	Maintenance lists have not been provided.	None.	Need maintenance data.
RM 1, 2	No disturbances provided.	Disturber equipment list not provided.	Maintenance lists have not been provided.	None.	Need disturbance, equipment, and maintenance data.
CRV 1	No disturbances provided.	Disturber equipment list not provided.	Maintenance lists have not been provided.	None.	Need disturbance, equipment, and maintenance data.

Summary

ELEMENT	DISTURBANCE ADEQUACY RATING	DISTURBER EQUIPMENT CAPTURE	MAINTENANCE ACTIVITIES WITHIN 90 DAYS	COMMENTS	ISSUES & RECOMMENDATION
CAM	4 / 10	Needs manifest check.	Maintenance lists have not been provided.	None.	Need improved disturbance and maintenance data.
HAB	6 / 10	Needs manifest check.	Maintenance lists have not been provided.	None.	Need maintenance data.
ATV	No disturbances provided.	Disturber equipment list not provided.	Maintenance lists have not been provided.	None.	Need disturbance, equipment, and maintenance data.
ICM	No disturbances provided.	Disturber equipment list not provided.	Maintenance lists have not been provided.	None.	Need disturbance, equipment, and maintenance data.

Weaknesses

- Maintenance Activity Data
  - GSE and IP elements
- Flight Manifests
  - RSA flights
- Equipment Lists
  - Payloads
  - RSA downstream elements
  - CRV, CAM, ATV, Prop Module, ICM
- Disturbance Descriptions
  - RSA & NASDA - wideband mechanical and acoustical
  - CRV, CAM, ATV, Prop Module, ICM
  - All - more direct measurements of force and sound power

Strengths

- Increased Testing
  - SARJ response
  - TRRJ response
  - US Lab response and transfer functions
  - RSA SM response
  - ESA equipment force and sound power
  - MSFC equipment force

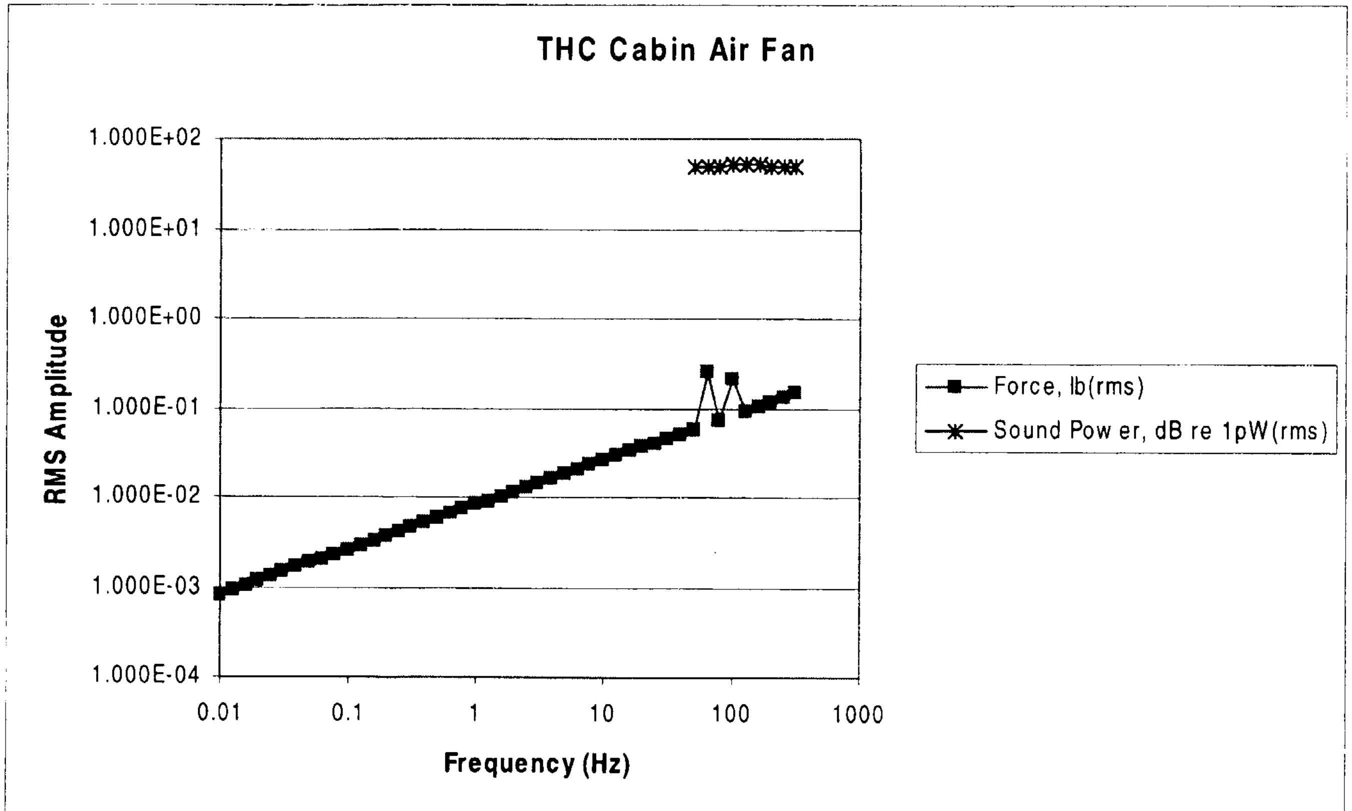
What's New

- New Database Format
- Disturbance Database Update
- US Lab Test Data
- MGAIT Web Site

New Database Format -
Typical Data Sheet (Partial)

Co. / Agency	BHV			
Item	Fan, THC, Cabin Air (375 W, nominal)			
Location (Nu	Ls6 (1), Lp6 (1)			
Duty	Continuous - only one of the THC fans is operational at a time.			
References	144			
Bibliography	1,2,11,17,26,38,52,55,56,71,75			
Comments	An imbalance force of 0.188 lbrms at 98.3 Hz and a subharmonic of 0.25 lbrms at 63 Hz is included in the 1/3OB levels below .			
OB Ctr Freq,	Time, s	Force, lb(rms)	Moment, in-lb(rms)	Sound Pow er, dB re 1pW(rms)
10		2.570E-02		
12.5		2.890E-02		
16		3.230E-02		
20		3.640E-02		
25		4.070E-02		
31.5		4.570E-02		
40		5.130E-02		
50		5.760E-02		4.750E+01
63		2.580E-01		4.750E+01
80		7.250E-02		4.750E+01
100		2.050E-01		5.080E+01
125		9.090E-02		5.080E+01
160		1.020E-01		5.080E+01
200		1.150E-01		4.760E+01
250		1.280E-01		4.760E+01
315		1.450E-01		4.760E+01

New Database Format -
Typical Data Plot



Disturbance Database Update

- FGB is VAC 1
- Node1 is VAC 1
- SM is updated to VAC 1R
  - Generic US Lab analytical data is removed
  - Vibration data at SM/FGB interface from RSCE SM test is included
- Z1 is VAC 2
- P6/S6 & P4/S4 are VAC4A
- US Lab is updated to VAC 5A
  - BHV analytical estimates are used for all items except AAA fan
- Airlock is unchanged
- S1/P1 is updated to include measured data from TRRJ tests
- S3/P3 is updated with preliminary data from SARJ tests
  - These data will be updated shortly with data currently being analyzed

Disturbance Database Update

- APM (COF) is updated with recent test data
  - Further study is needed here to fully understand ESA data descriptors/configurations
- JEM EF is updated with new pump and ICS EF sim data
- Node 2 is updated with DAC 7 USL disturbance descriptions for identical equipment items
- Node 3 is updated with DAC7 Hab disturbance descriptions for identical equipment items
- Hab data is reinserted in database
- Payloads, CAM, other RSA elements, and crew are unchanged

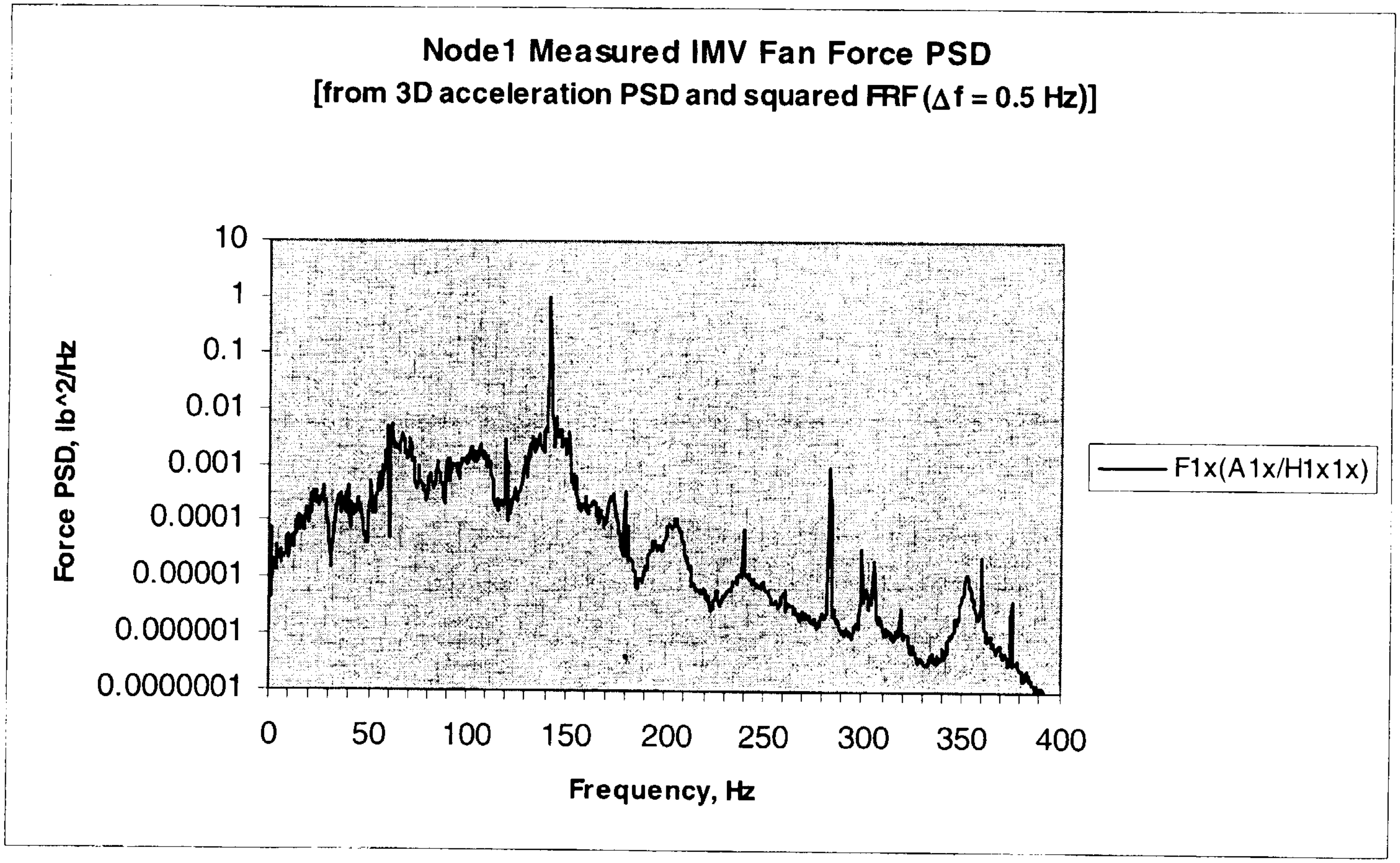
MGAIT Web Site

- Http://iss-www.jsc.nasa.gov/ss/issapt/payofc/OZ4/mgait_pages/mgait.html
- Includes
  - Requirements Documents
  - Disturbance Databases (in 2 weeks)
  - Transfer Functions
  - Verification Reports
  - Special Studies
  - US Lab Test Data
  - Vehicle and Payloads Items of Interest

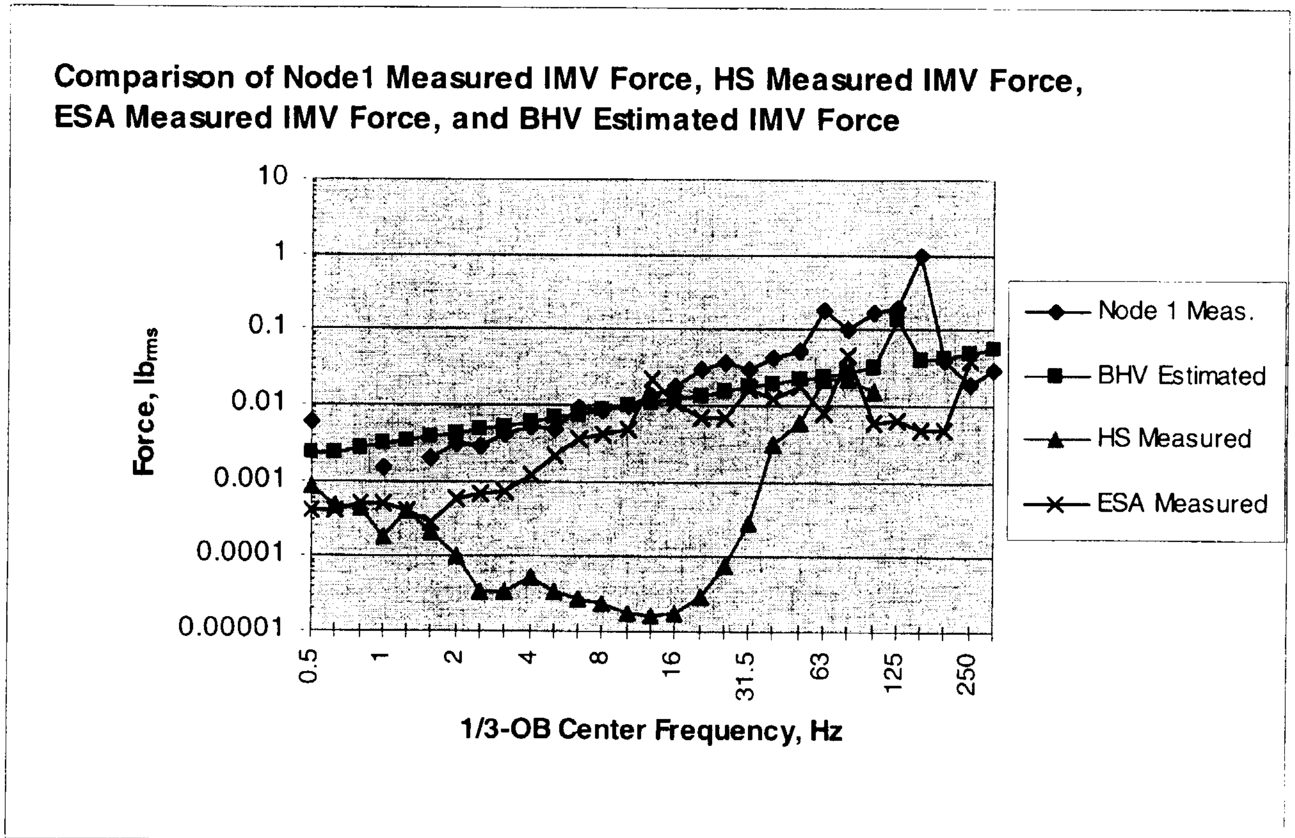
Comparison of Disturbance Descriptions

- Node 1 measured narrowband IMV force PSD
- Comparison of estimated and measured 1/3-OB rms IMV force descriptions
- Comparison of estimated and measured 1/3-OB rms AAA force descriptions

Node1 Measured IMV Fan Force PSD

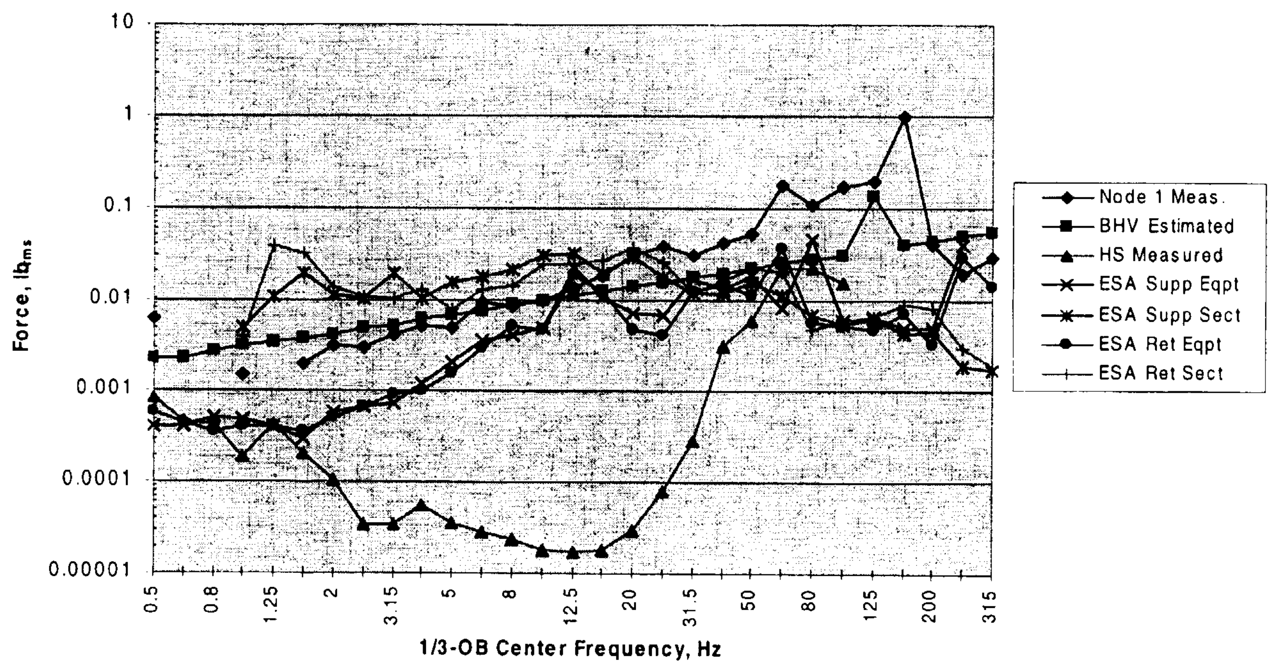


Comparison of Node1 Measured IMV Force, HS Measured IMV Force, ESA Measured IMV Force, and BHV Estimated IMV Force

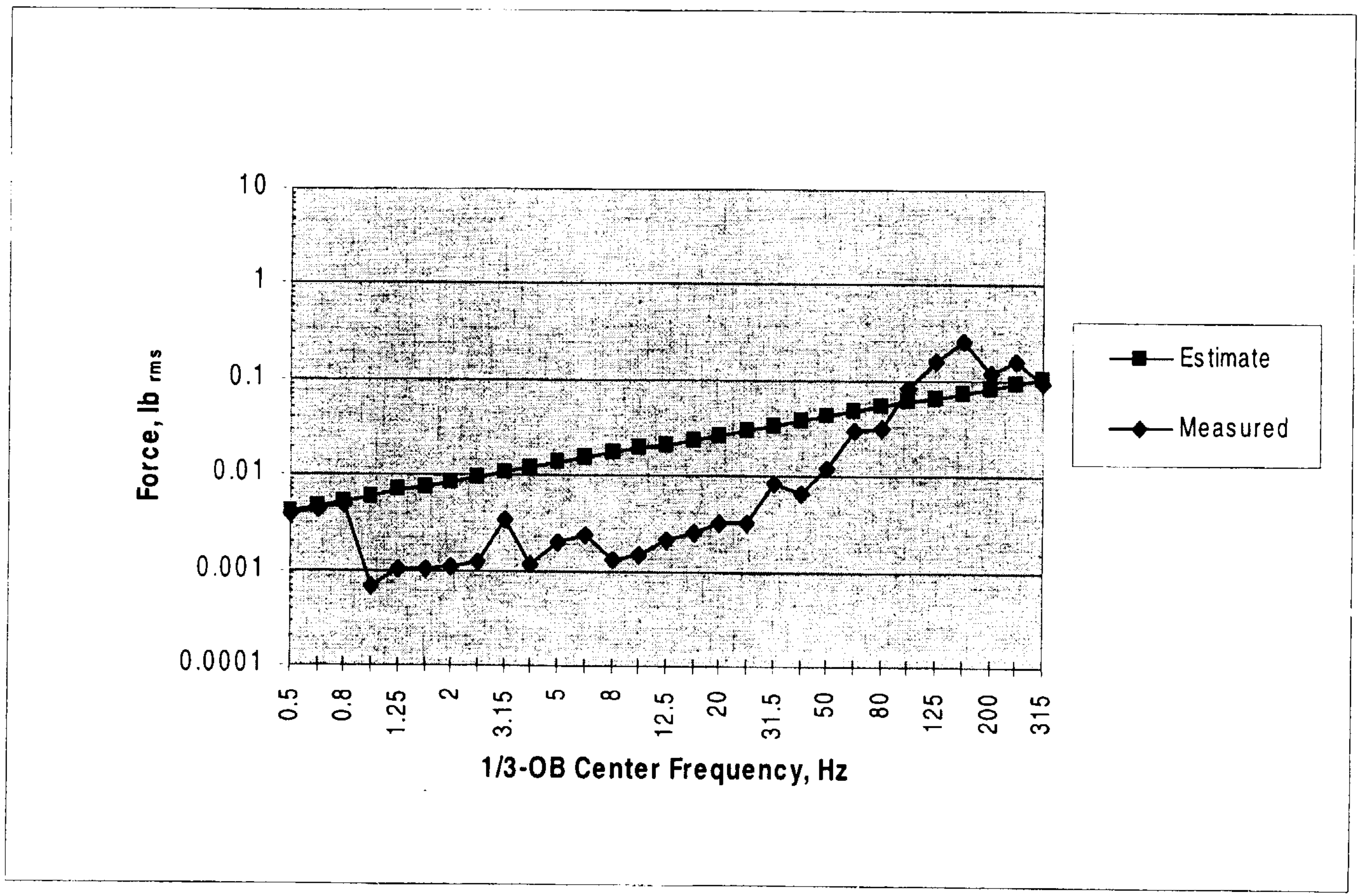


Comparison of Node1 Measured IMV Force, HS Measured IMV Force, ESA Measured IMV Forces, and BHV Estimated IMV Force

Comparison of Node1 Measured IMV Force, HS Measured IMV Force, ESA Measured IMV Force, and BHV Estimated IMV Force



Comparison of Measured and Analytical AAA Fan Forces



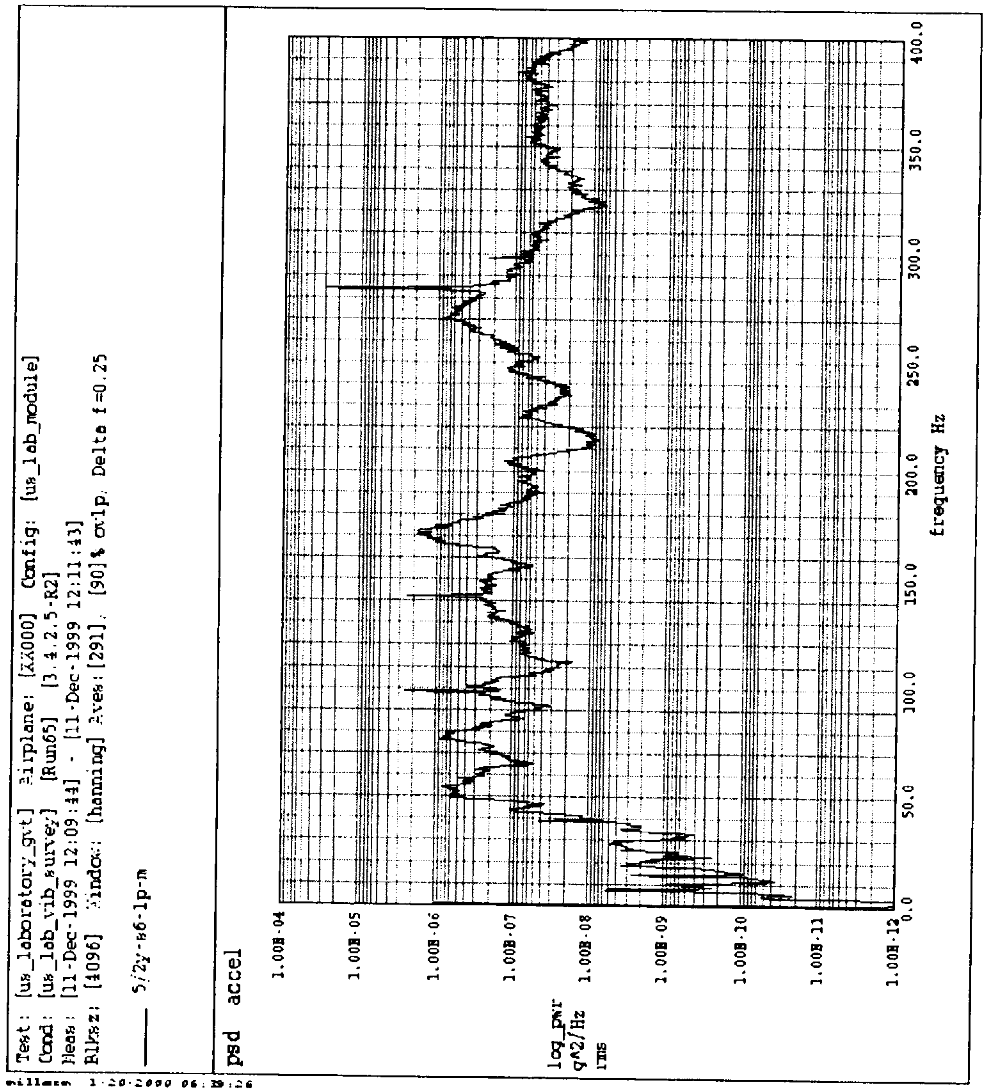
US Lab Test

- Early Test Results
- Typical Narrowband Acceleration PSD
- Typical 1/3-OB rms Accelerations

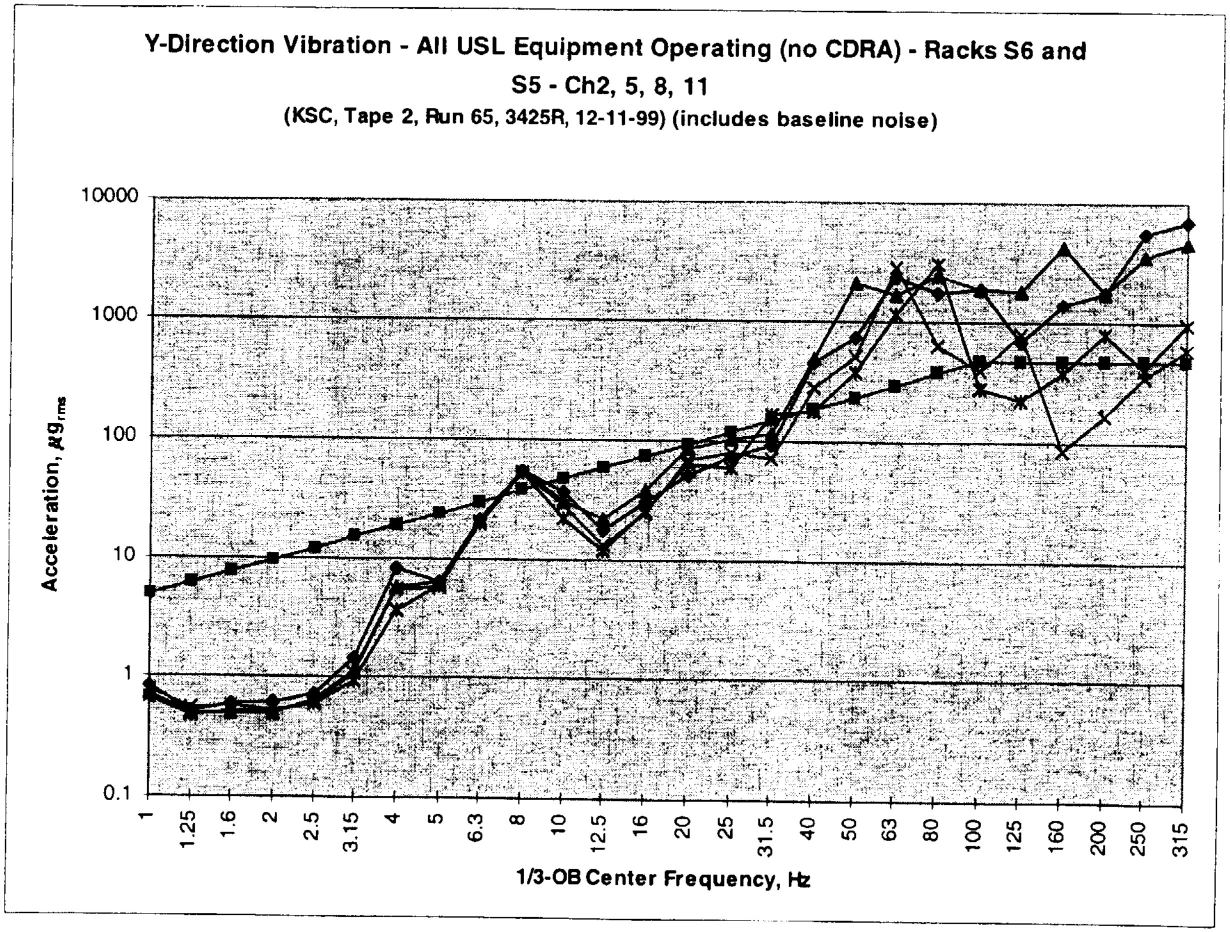
Early USL Test Results

- Accel PSD and 1/3-OB show running speed and blade passage tone peaks and flow induced broadband signals
- High frequency response attenuates with distance for both rack and standoff positions
- Impulse induced TF indicate that the USL rack and structure is more heavily damped than assumed in analytical predictions
- Measured accelerations are less than predicted responses
- As the data evaluation process progresses, more useful information will be obtained
  - Disturbance force and acoustic power of equivalent rack sources will be extracted from measured responses using measured transfer functions
  - Structural damping and acoustical absorption will be quantified from transfer function data
  - These will be useful for future element verification and for sustaining engineering support activities

Typical All Source (except CDRA) Induced Acceleration PSD



Y-Direction Vibration - All USL Equipment Operating (no CDRA) - Racks S6 and S5



20010197 26 S 125 74
15/13

Paper Number: 13

ISS microgravity requirements and verification

Fred Henderson
Teledyne Brown Engineering
Houston, Texas

With the completion of a Payload Microgravity Requirement for Space Station for US payloads, the means of payload verification to satisfy the new requirements must be established. While programmatic aspects deserve some attention, the immediate problem is to define methods that successfully verify new techniques on largely unverified on-orbit attachment structure. The MGAIT has developed methods to accomplish integration and verify ISS structure behavior if satisfactory data is provided by payloads. However, the means of payloads to provide useful data is new and unproven. Although it is permissible for payloads to be verified on the basis of analysis alone, it is important to realize that few, if any, have the necessary experience to examine hardware components and anticipate their likely disturbances without performing tests. Furthermore, payloads which change subsystems and sub-payloads on-orbit need verified payload models to perform verification from the ground. The purpose of this presentation is to suggest how this integration validation process might proceed.

ISS Microgravity Requirements and Verification

Microgravity Measurement Group - 2000

TELEDYNE
BROWN ENGINEERING, INC.
A Teledyne Technologies Company

Fred Henderson
OZ3/PEI
July 12, 2000

Methods of Verification

- The Payload Verification Process Defined by SSP 57011
- ISS 57000 PIRN 110H Requirements
- Methods of Verification
  - Analysis Method Defined in PIRN 110H
  - Test Methods Defined in the Generic Payload Microgravity Control Plan (Annex to SSP 57010)
  - Economical Methods for Payload Developer In-House Verification

Fred Henderson
July 12, 2000

Verification Approach (SSP 57011)

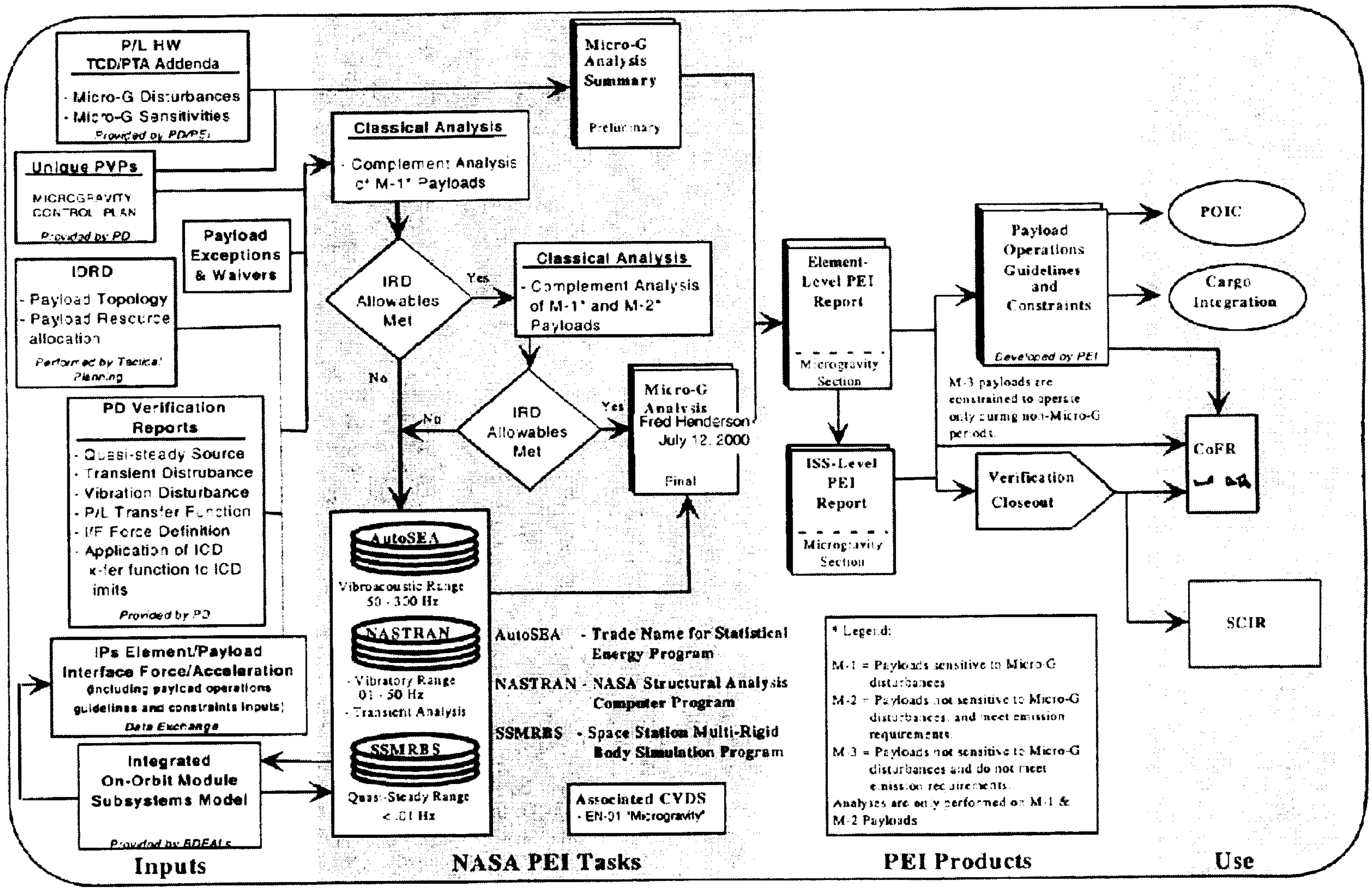


Figure 3.4.11-11: PEI Element-Level and ISS-Level Microgravity Analysis Process

Fred Henderson
July 12, 2000

3

USL Stage Verification Analysis

- If each payload meets the allocation defined by IRD requirements, then analysis is limited to the development of Operations Guidelines and Constraints restrictions
- If the RSS of payload contributions in each one-third octave exceeds the IRD limit but is less than the US Lab limit, then simplified stage element analysis is sufficient (stage waiver can be granted to payload)
- If the US Lab limit is exceeded then ISS stage dependent analysis and request for waiver/deviation will be required for the payload to operate
- Waivers/deviations are submitted to the OZ-3 lead Payload Technical Review (PTR), the same group that approves ISS payload requirements changes. The PTR responds to recommendations from Payload Engineering and Integration (PEI) and other interested parties.

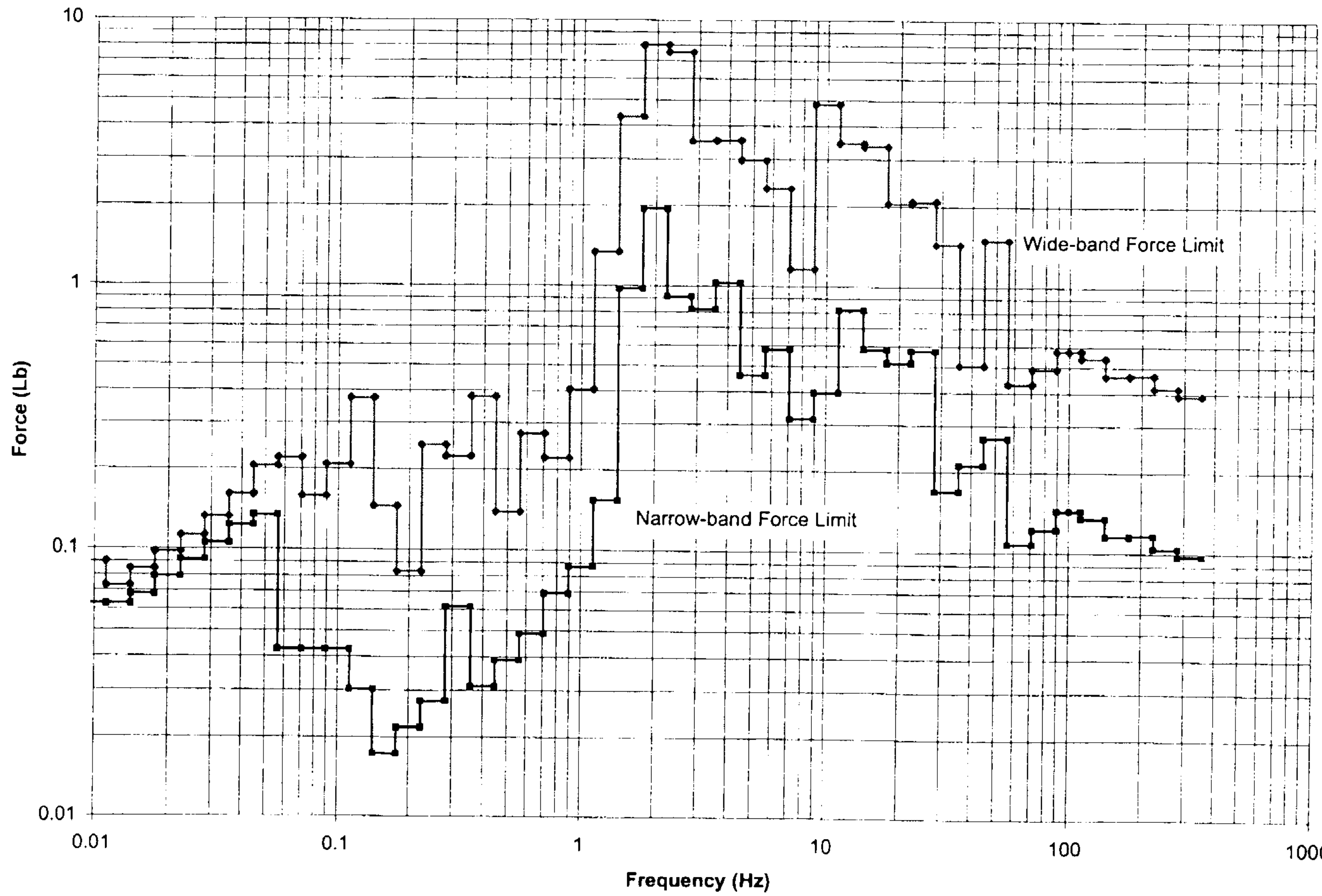
International Partner Stage Verification Analysis

- Per pending SSP 57011 revision, payloads exceeding IRD limits must submit a payload waiver request to the element's payload project office to obtain approval
  - If no other IP payloads are affected then the element payload project office may approve the waiver
  - If IP payloads are affected then the waiver must be forwarded to the affected IP payload project office, with a recommendation for disposition
  - If concurrence cannot be given by the affected IP, the waiver will be forwarded to the ISS PTR for development of a recommendation to the MPICB
  - The PTR will request support from international partners, Payload Operations (MSFC), the Vehicle, other OZ offices, and the payload community to develop a MPICB recommendation
- Unique (stringent) microgravity requirement approval will be requested likewise through the element's payload project office and forwarded when necessary to the ISS PTR as a request for waiver

Unofficial - For discussion Purposes Only

Fred Henderson
July 12, 2000

PIRN 110H Force Limit
at Integrated Rack Interface

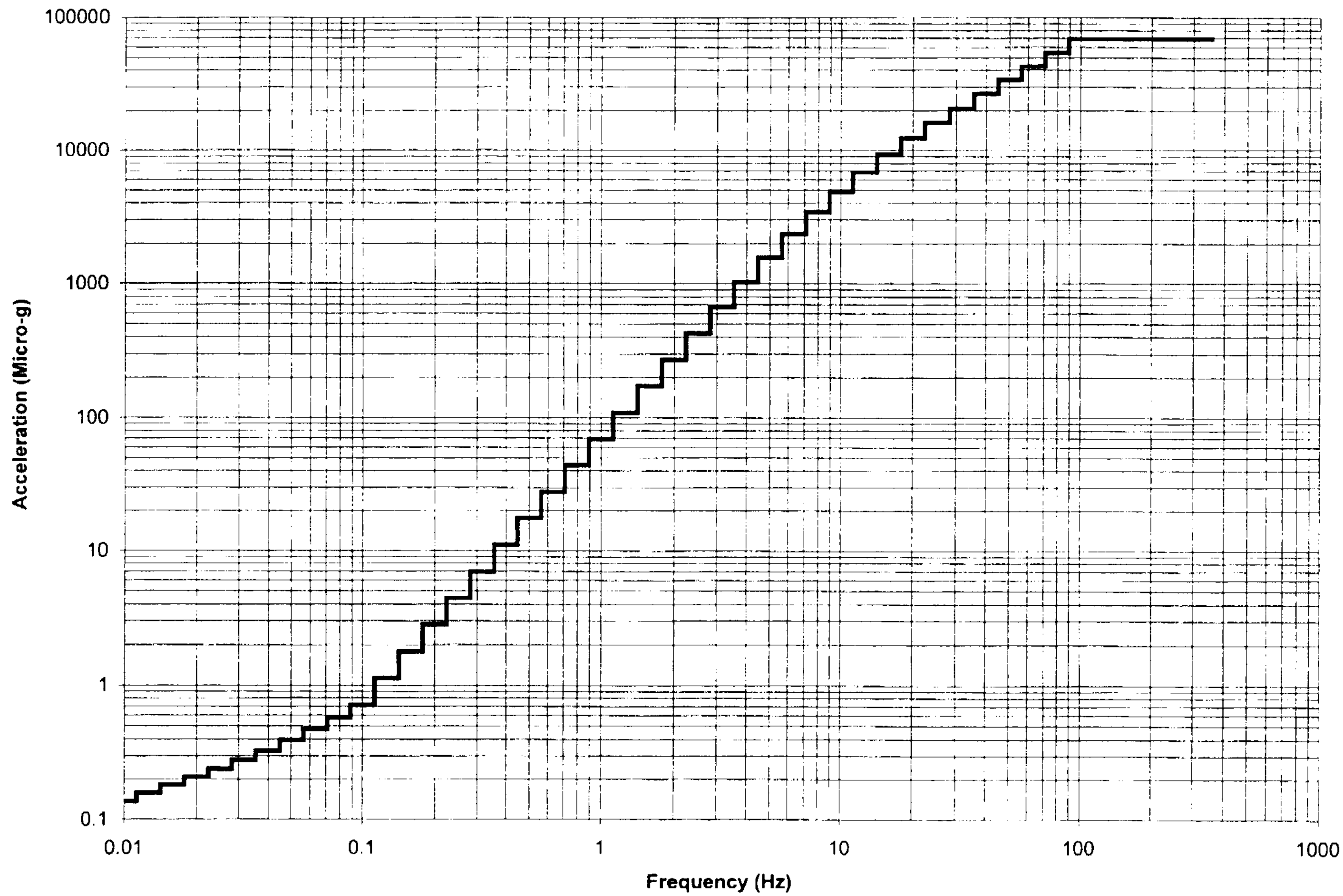


6

Fred Henderson
July 12, 2000

PIRN 110H Acceleration limit from outside sources

Response of ARIS Rack to Modeled Rack

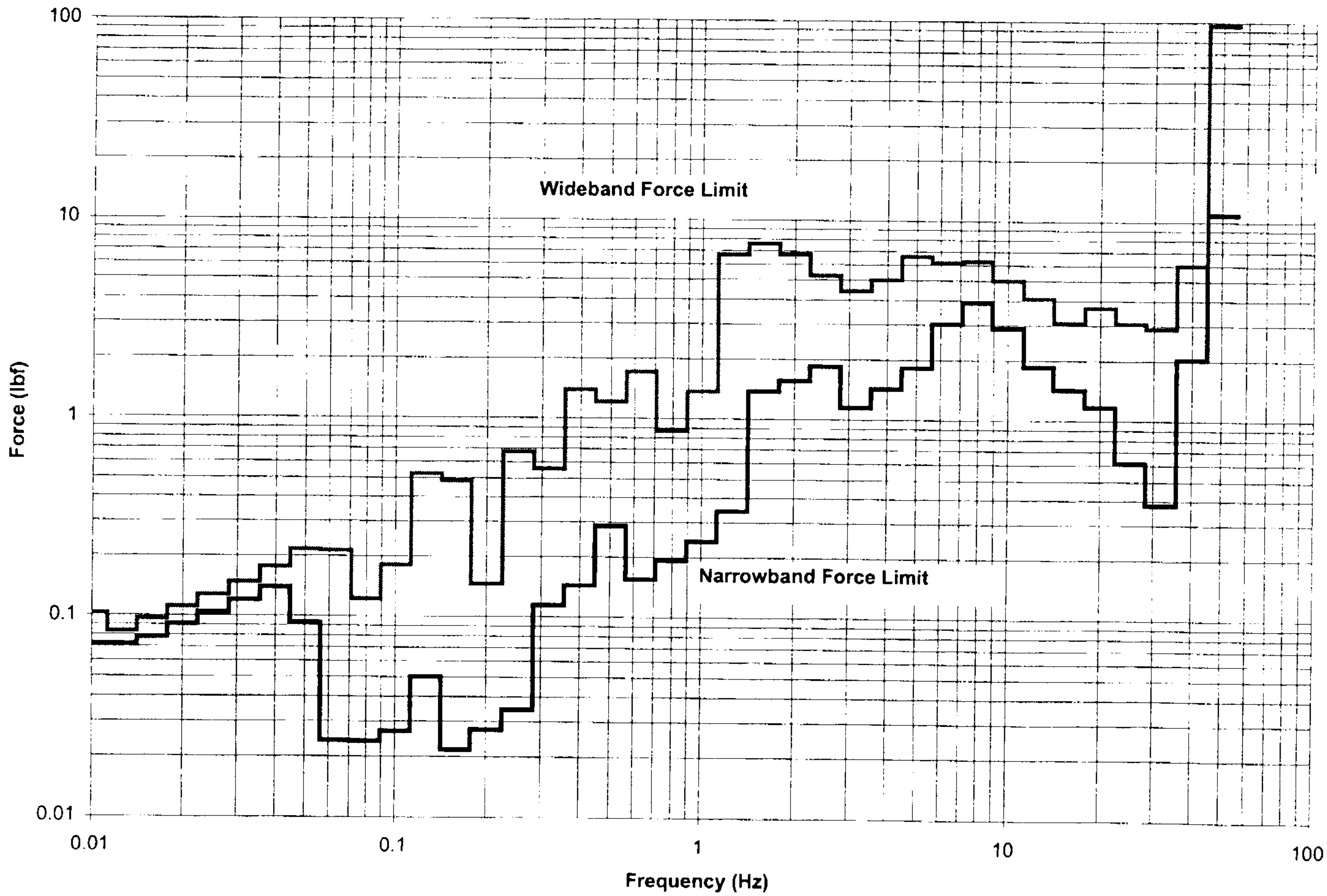


7

Fred Henderson
July 12, 2000

PIRN 110H ARIS Force Limit from internal sources

On-Board Force Limits to Meet Off-Board Force Limits



8

Fred Henderson
July 12, 2000

The Argument for Test

Minimal Payload Test Capability Recommended During Payload Development

- Support Component Selection
- Provide Immediate Cause/Effect Structural Experience
- Shorten Model Verification Cycle
- Learn Quickly of Non-Obvious Problems

Unofficial - For discussion Purposes Only

Fred Henderson
July 12, 2000

Hazards of Direct Force Measurement

- Difficult to isolate both payload and large interface mass from background vibration
- Spring constant of sensitive force gauges can be low (shift modes or introduce new modes)
- Response of force measurements typically decreases at higher frequencies (measure displacement)
- Sensitivity limited by noise floor and hysteresis
- Multiple sensors necessary to capture linear and angular forces, each of which affects (decreases) the sensitivity of others

Unofficial - For discussion Purposes Only

Fred Henderson
July 12, 2000

Typical Accelerometer Requirements

- Frequency Response from 0.1 Hz to 300 Hz
  - Low Frequencies require relatively large mass displacements - Calculation
- Dynamic Range from 1 μg to 100000 μg
  - 1 μg for 10:1 measurement of .02 lb-f from 2000 lb-m rack
  - 100,000 μg to tolerate
    - Simultaneous high frequency vibration from accelerometer located local modes
    - Random Peaks (3:1 above RMS) and Transients
  - High resolution not necessarily sufficient - Check drift (1/F noise = accuracy)
  - Calibrated Low-Pass filter permits expanded dynamic range with low-drift
- Noise Floor less than 1E-11 μg^2 / Hz for 1500 lb-m rack
  - .03 lb-f .14 to .19 Hz
  - .1 lb-f 56.2 to 70.8 Hz
- Leveling Capability or High-Pass filter (to remove g * sin(tilt) bias)

Unofficial - For discussion Purposes Only

11

Fred Henderson
July 12, 2000

High Frequency Disturbance Measurement

- Payload on Air Bags or Foam useful above 10 Hz
  - Mass with air bag natural frequency 1/2 or less than first frequency of interest
  - Rigid fixture structure to be a minimum of twice the highest frequency of concern
  - Obtain sufficient vertical stiffness or damping to avoid tilt modes (G * sin (tilt) error)
  - Measure rotational vibration and translation in horizontal plane with unbiased accelerometer (it is difficult to measure 1g + 1 mg vibration vertically)
  - Measure X,Y, Z translation near radials from CM (one accelerometer per axis)
  - Measure X,Y,Z rotation tangentially at known distances on each side of the center of mass (two accelerometers per axis)

Unofficial - For discussion Purposes Only

12

Fred Henderson
July 12, 2000

Low Frequency Disturbance Measurement

- Pendulous Fixture Recommended for Low or Broad Measurement
  - Accelerometer Located Near the Center of Percussion Height near the Center of Rotation in the Horizontal Plane (Impervious to Fundamental Pendulum Modes)
  - Air Bags Under Outer Fixture to Dampen Pendulum Modes while Providing Vertical High Frequency Vibration Attenuation
  - High Frequency Performance Limited by Fixture Modal Response (.01 to 50 Hz typical)
- Crane Suspended Measurements are Possible if Work-around is available for problem modes
  - Cable Vibration Modes
  - Rack-on-hook swing mode
  - Vertical bounce modes

Unofficial - For discussion Purposes Only

Fred Henderson
July 12, 2000

Analysis of Test Data

- Determine Interface Force
  - Determine source force for each frequency by F=m*a Calculation
  - If only integrated payload measurements are available, determine source force via model that would cause the measured response (Divide response by source to interface transfer function)
  - Use integrated payload to simplified element model to determine interface force
- Validate FEM/SEA Models
  - If source measurements, integrated payload measurements and integrated payload model are available, compare test data to free-free model predictions
  - Adjust payload model, simplified element/ISS model or source model if necessary

Unofficial - For discussion Purposes Only

Fred Henderson
July 12, 2000

2000 4728

S125 76
16 Pg

MGMG #19

Paper Number: 14

The role of on-orbit stage-specific assessment of the ISS microgravity environment in meeting ISS Super Board requirements

Roy Christoffersen & Craig Schafer
Science Applications International Corporation
Houston, Texas

The International Space Station (ISS) is subject to a review process, the Super Board, in which the on-orbit performance of the Station during assembly up to the end of 2003 is evaluated at specific milestones to determine Boeing's award fee. The evaluation criteria will include system functionality and science capability, both areas that can be expected to include microgravity performance. To support the Super Board, the ISS Microgravity Analysis and Integration Team (MGAIT) is exploring the possibility of performing a series of on-orbit assessments of the ISS microgravity environment that are timed to support the Board's milestones. These assessments would rely heavily on structural dynamic and vibroacoustic analytical models that are refined with on-orbit acceleration measurement data acquired at specific assembly stages. At each milestone, the refined analytical models would be used to predict the expected microgravity performance of the Assembly Complete (AC) station. The results would then be shared with the Super Board.

Present Super Board milestones exist at assembly stages 7A, UF-2, 12A.1, and 1 J/A, culminating in a final meeting at the end of December of 2003. To accommodate each of these milestones, a cycle consisting of on-orbit measurement, analysis and AC-environment prediction is being considered which would follow the major changes in the Station's global dynamic and disturbance characteristics that precede each milestone. The first analysis cycle based on this scheme, occurring prior to 7A, would include data and supporting analysis from the Active Rack Isolation System-ISS Characterization Experiment. Other analysis cycles would occur after on-orbit integration of the S0 truss segment (pre-UF-2), Solar Power Platform, P3/4 truss and Solar Alpha Rotary Joint (SARJ) (pre-12A.1), S3/4 truss, SARJ and Node 2 (pre-1 J/A) and the Japanese Experiment Module – Pressurized Module (pre-final Board).

Initial MGAIT plans call for the on-orbit measurement and analysis cycles to refine assembly-stage-specific analytical models by comparing their results to data from the Space Acceleration Measurement System-II (SAMS-II), Microgravity Acceleration Measurement System (MAMS), and Internal Wireless-based (IWIS) accelerometer systems. The improvements, obtained at each assembly stage, in the fidelity of the disturbance forcing functions, transfer functions, and ARIS-system model for the on-orbit Station components would then be used to assess the degree of conservatism and fidelity of the AC analytical model. Because accelerometers will record the integrated responses from disturbances from both the vehicle and payloads, the stage-specific analytical models would need to include the effects of payloads.

The Role of On-Orbit Stage-Specific Assessment of the ISS Microgravity Environment in Meeting ISS Super Board Requirements

Roy Christoffersen and Craig Schafer

Space Station Payloads Office (OZ4)

Science Applications International Corporation

The ISS On-orbit Award Fee Plan

- Boeing's award fees for ISS have to date been based on its "on-ground" performance on cost, technical, schedule and managerial areas.
- However, a percentage of these fees is "at risk" of take-back based on criteria tied to Boeing's on-orbit performance.
- The <u>On-orbit Award Fee Plan</u> defines 7 milestones during assembly, from stage 2R to the end of calender year 2003, at which on-orbit performance evaluations will be made.
- The evaluations are performed by a "Superboard" who makes recommendations to the Performance Incentive Determining Official (PIDO, JSC Center Director) who makes the final decisions
- Superboard has Government and Non-Government (NRC, ACISS etc.) members, Chair is ISS Program Manager

Superboard Evaluation
Areas of Emphasis

Area 1 - Assembly configuration completed as planned

- Five levels of compliance criteria (% score)

Area 2 - Station systems operating to plan	**Score**
• Full functionality, with only minor deficiencies; **meets specifications** / supports expectations	91-100%
• Functionality limited, with some deficiencies; supports basic expectations	71-90%
• Functionality limited; significant work-arounds required; supports minimal expectations	51 - 70%
• Functionality severely limited; **re-design required** and/or highly constrained operations result	1-50%
• Total system failure; i.e., it is unable to perform to any degree	0%

Superboard Evaluation
Areas of Emphasis (con't)

Area 3 - Science capabilities and timelines supported	Score
• All significant science objectives supported successfully by vehicle performance	91-100%
• Science objectives moderately degraded due to vehicle performance	71-90%
• Significant science objectives partially supported by vehicle performance	51-70%
• Science objectives severely degraded due to vehicle performance	1-50%
• Science objectives not supported to any degree, due to vehicle performance	0%

Award Fee "Take-Back" Scheme

Milestone Event	Estimated Date	Percent Cumulative On-Ground Award At Risk	Cumulative On-Ground Award Fee Period	Areas of Evaluation Weightings		
				Assembly	Operations	Science
2R	Oct-00	15%	4/96 - 9/00	70%	30%	0%
7A	May-01	40%	10/00 - 5/01	40%	50%	10%
UF-2	Feb-02	60%	6/01 - 2/02	40%	50%	10%
12A.1	Mar-03	80%	2/02 - 3/03	40%	50%	10%
1 J/A	Re-assign?	90%	Re-assign?	40%	50%	10%
10A	Oct-03	100%	TBD	40%	50%	10%
31 Dec '03	Firm Date	Special Rules*		0%	50%	50%

*On-orbit award fee dollars that were "lost" in previous milestone evaluations can be re-gained at the final milestone

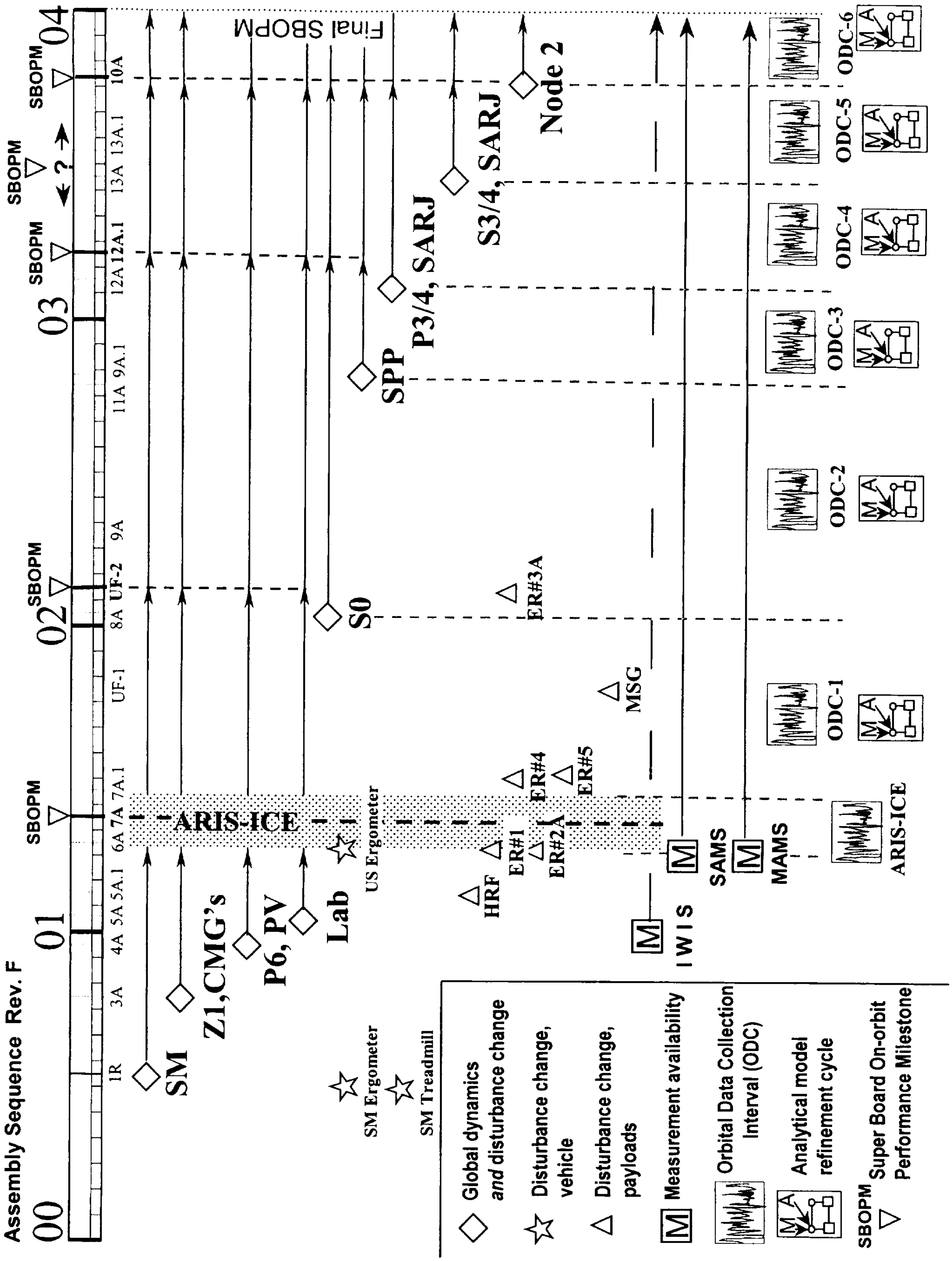
On-orbit award fee calculation at a particular milestone:

On-ground award fee earned over preceding on-ground fee period **X** % of award at risk at that milestone **=** Maximum on-orbit fee that can be earned at milestone

Maximum on-orbit fee that can be earned at milestone **X** Milestone evaluation score (0-100%) **=** Total on-orbit award fee earned at milestone

The MGAIT and the Superboard

- The Superboard will receive an assessment of Boeing's performance from the ISS Program Office
- This will include input from ISS Payloads (Code OZ), with support from appropriate members of the Microgravity Analysis and Integration Team (MGAIT)
- Boeing also has the option of contributing a self-evaluation
- We will outline here a <u>proposed</u> approach for performing on-orbit microgravity measurement, and on-ground analysis, on a schedule to support the Superboard milestones



Assembly Sequence Rev. F
00
01
02
03
04
1R
3A
4A
5A
5A.1
6A
7A
7A.1
UF-1
8A
UF-2
9A
11A
9A.1
12A
12A.1
13A
13A.1
10A
SBOPM
Final SBOPM
SM
Z1,CMG's
P6, PV
Lab
S0
SPP
P3/4, SARJ
S3/4, SARJ
Node 2
ARIS-ICE
SM Ergometer
SM Treadmill
US Ergometer
HRF
ER#1
ER#2A
ER#4
ER#5
ER#3A
MSG
IWIS
SAMS
MAMS
ODC-1
ODC-2
ODC-3
ODC-4
ODC-5
ODC-6
Global dynamics and disturbance change
Disturbance change, vehicle
Disturbance change, payloads
Measurement availability
Orbital Data Collection Interval (ODC)
Analytical model refinement cycle
Super Board On-orbit Performance Milestone

Measurement and analysis alignment with SBOPMs

SBOPM	Receives on-orbit data from:	Station elements added:	Analytical MG environment prediction based on:
7A	Early ARIS-ICE	SM, Z1, CMGs, P6, PV, Lab	6A
UF-2	Final ARIS-ICE	+ payload racks only	6A + rack disturbances
	ODC-1	+ payload rack only	6A + rack disturbances
12A.1	ODC-2	+ S0	8A + rack disturbances
	ODC-3	+ SPP	9A.1 + rack disturbances
10A	ODC-4	+ P3/4, SARJ	12 A + rack disturbances
	ODC-5	+ S3/4, SARJ	13 A + rack disturbances
Final	ODC-6	+ Node 2	10 A + rack disturbances

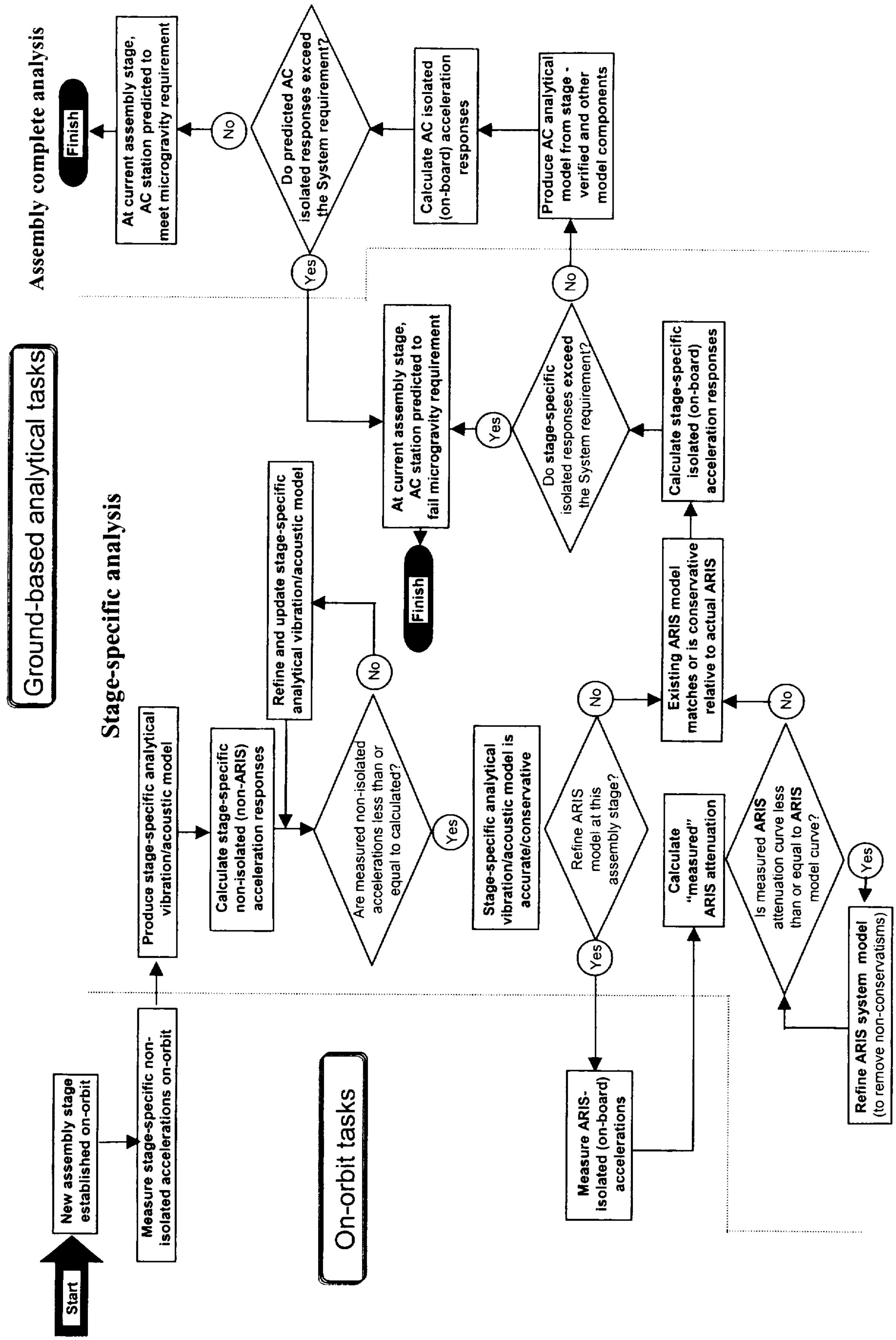
Findings:

1) 7A milestone (ms) has inadequate time window; receives minimal MG data
2) UF-2 ms well positioned for ARIS-ICE data
3) 12A.1 ms well positioned for ODC-2 data, probably too tight for ODC-3
4) Likewise 10A ms too tight to get ODC-5 data for S3/4 done in time
5) ODC-6 too close to Final SBOPM to deliver
6) Remaining "floating" milestone should go between UF-2 and 12A.1 at 9A.1

On-orbit measurement, analysis and MG environment prediction strategy

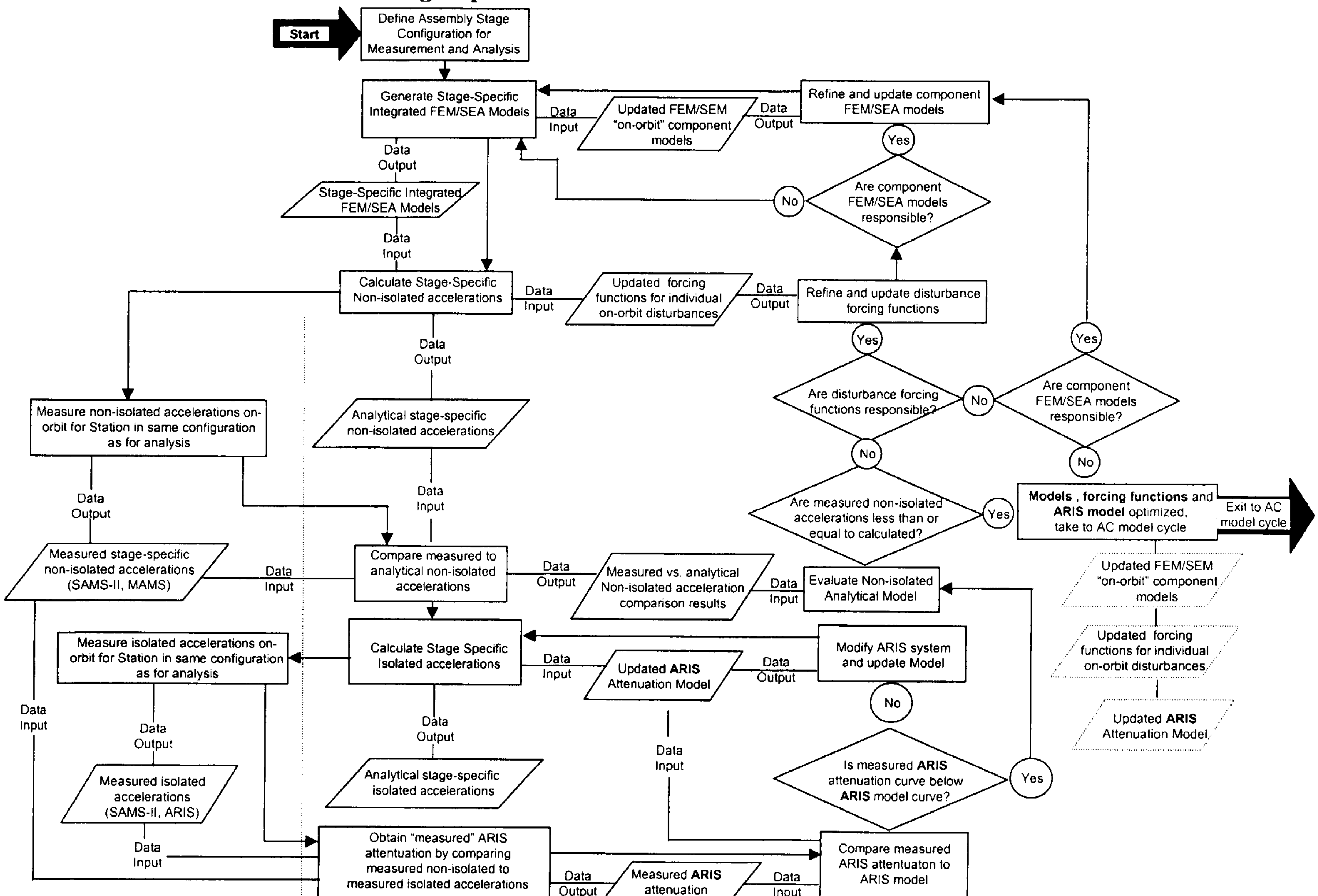
- During each ODC interval, microgravity measurement data will be accumulated
- An assembly-stage-specific FEM/SEA analytical model appropriate to that ODC will be generated beforehand
- At some point during the ODC, a comparison cycle between the on-orbit data and the stage-specific analytical model will begin.
- The stage-specific analytical model will be refined, and its conservatism/non-conservatism assessed
- Refinements to the stage-specific model will also be incorporated into an evolving Assembly Complete analytical model
- The evolved AC analytical model will be used to predict the AC environment prior to the next Superboard milestone
- Comparison of the predict AC environment to ISS requirements will be shared with the Superboard

On-orbit measurement, analysis and MG environment prediction flowchart



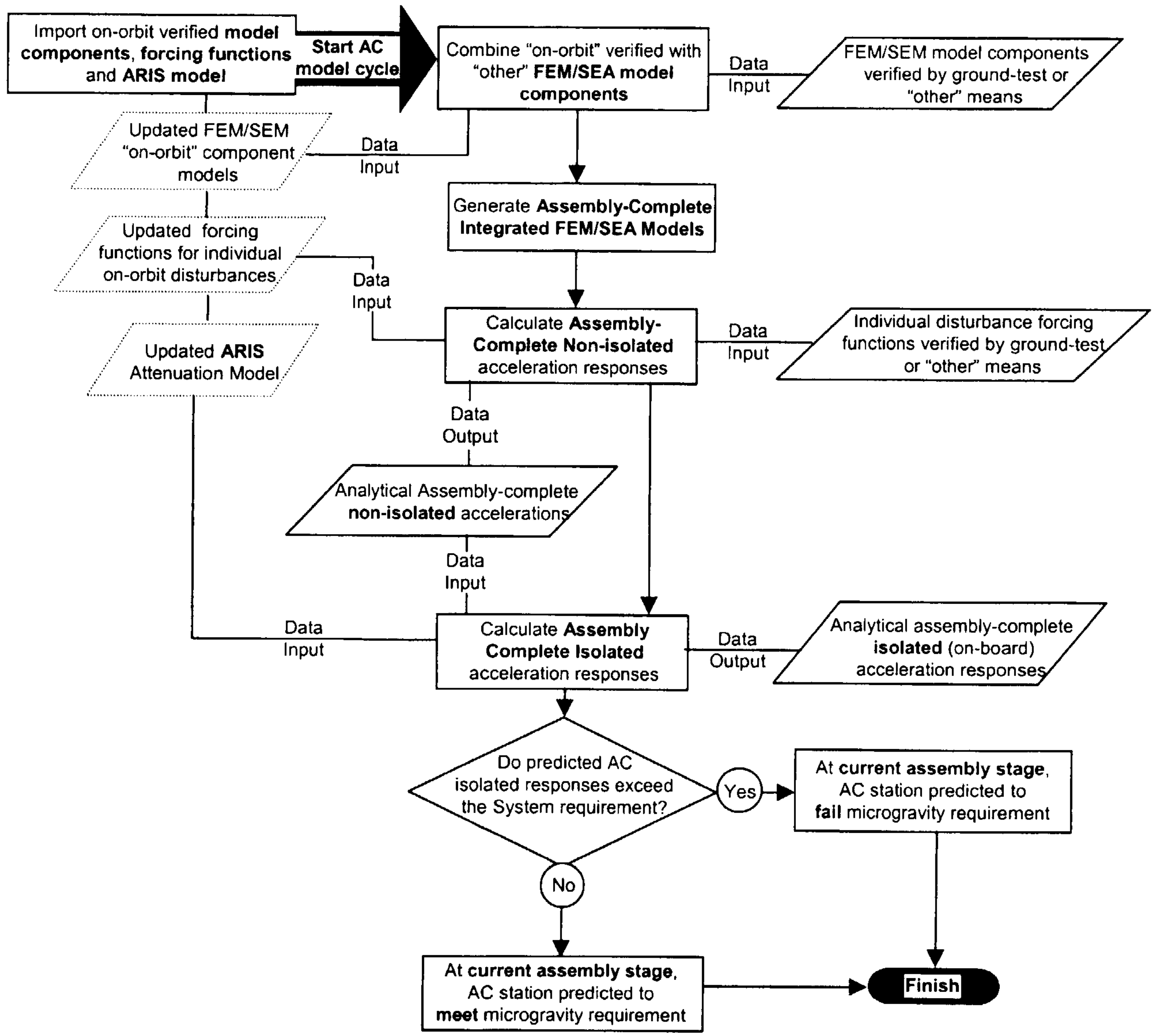
Process 1: Stage-Specific Measurement and Analysis Cycle

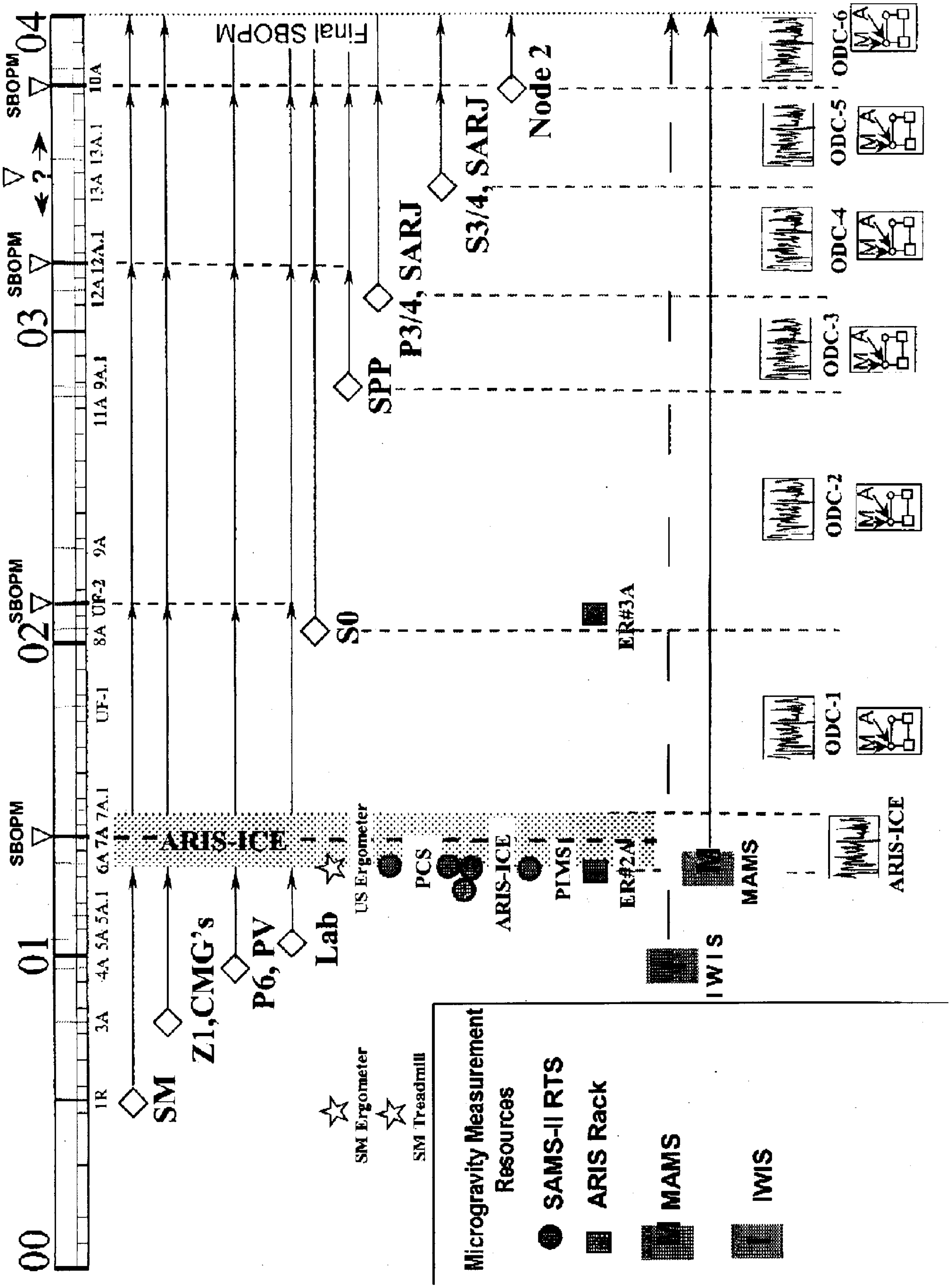
Refinement of the Stage Specific FEM/SEA models based on on-orbit measurements



Process 2: AC Environment Prediction

Assembly-Complete MG environment prediction using AC analytical model components "refined" during stage-specifc cycle, and "other" components not refined on orbit





00
01
02
03
04
SBOPM
Final SBOPM
1R
3A
4A 5A 5A.1
6A 7A 7A.1
UF-1
8A UF-2
9A
11A 9A.1
12A 12A.1
13A 13A.1
10A
SM
Z1,CMG's
P6, PV
Lab
S0
SPP
P3/4, SARJ
S3/4, SARJ
Node 2
ARIS-ICE
US Ergometer
PCS
ARIS-ICE
PIMS
ER#2A
ER#3A
MAMS
IWIS
ARIS-ICE
ODC-1
ODC-2
ODC-3
ODC-4
ODC-5
ODC-6
SM Ergometer
SM Treadmill
Microgravity Measurement Resources
SAMS-II RTS
ARIS Rack
MAMS
IWIS

Conclusions

- The Superboard will be where Boeing and the MGAIT get down to business (literally) on the ISS microgravity requirement
- SBOPMs are poorly aligned with Rev. F Assembly Sequence
  - Former 1 J/A milestone must be re-assigned, suggest 9A.1 to meet MG needs
  - On-orbit microgravity evaluation strategy does not "fit" well with SBOPM timing
- Proposed plan of MG environment prediction to support SBOPMs will require:
  - Producing additional stage-specific MG analytical models beyond that for 6A
  - Additional microgravity measurement resources
  - More thought to realistic and better integrated measurement/analysis schedule relative to SBOPMs

MGMG #19

Paper Number: 15

ISS assembly sequence

Steve DelBasso
The Boeing Company
Houston, Texas

The current assembly sequence and schedule of the ISS Program will be reviewed in this presentation. Emphasis will be placed on microgravity science and environment features of the assembly phase.

BOEING

ISS Assembly Sequence

Microgravity Measurement Group Meeting
Cleveland, Ohio
July 12, 2000

Steve Del Basso

Structural Analysis Microgravity Team
Boeing
502 Gemini Avenue
Houston, Texas
281-853-1603

Presentation Overview

- Revision E Assembly Sequence
- SEMDA Lab Stage Images(Lockheed/Martin)
- Selected Mass Properties
- Microgravity Period Durations

Assembly Complete Configuration

Interim Assembly Sequence, Revision E - 5, CR3412A
4/18/00

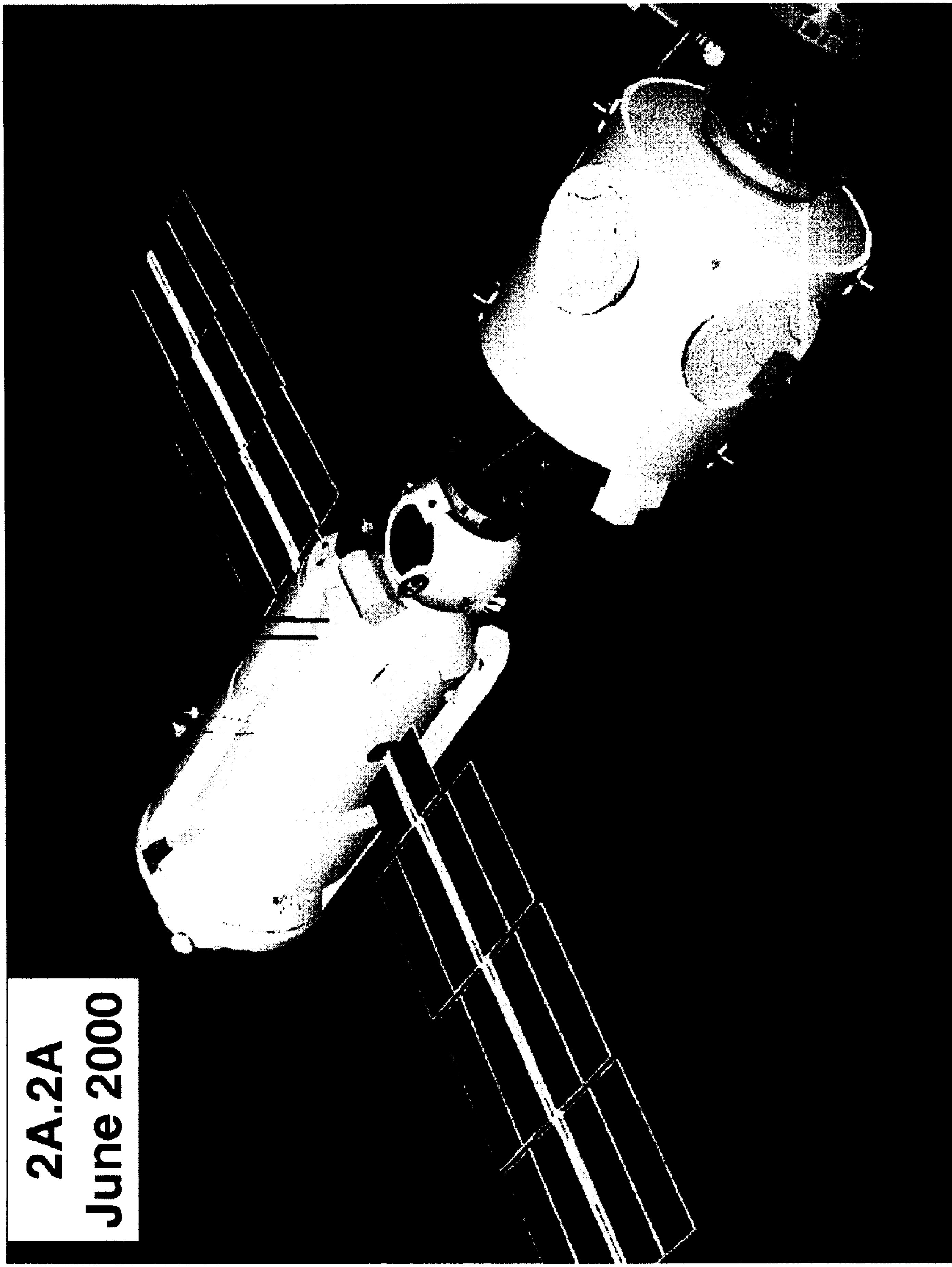
Launch Date	Flight	Delivered Elements
20-Nov-98	1A/R	FGB (Launched on PROTON launcher)
4-Dec-98	2A	Node 1 (1 Stowage rack), PMA1, PMA2, 2 APFRs (on Sidewall)
27-May-99	2A.1	Spacehab Double Cargo Module; OTD, Strela Components (on ICC)
24-Apr-00	2A.2A	Spacehab Double Cargo Module; Strela Components (on ICC)
12-Jul-00	1R	Service Module (Launched on PROTON launcher)
31-Jul-00	1P	Progress-M1
19-Aug-00	2A.2B	Spacehab Double Cargo Module; ICC
14-Sep-00	2P	Progress-M1
21-Sep-00	3A	Z1 truss, CMGs, Ku-band, S-band Equip; PMA3, ETSD (SLP); 2 Z1 DDCUs (Sidewall)
30-Oct-00	2R	Soyuz-TM (a)
30-Nov-00	4A	P6, PV Array (6 battery sets) / EEATCS radiators, S-band Transponder
12-Dec-00	3P	Progress-M
18-Jan-01	5A	Lab (5 Lab System racks); PDGF, SASA (on Sidewalls)
1-Feb-01	4P	Progress-M1
15-Feb-01	5A.1	Lab Outfitting (6 Sys racks, RSRs, RSPs, ISPR) (on MPLM); EAS, PFCS, LCA, ESP, and RU (on ICC) (c)
3-Mar-01	4R	Docking Compartment 1 (DC1), Strela
12-Apr-01	5P	Progress-M
19-Apr-01	6A	RSPs, RSRs, ISPRs (on MPLM); UHF; DCSU (on Sidewall);SSRMS (on SLP) - (b)
30-Apr-01	2S	Soyuz - TM
17-May-01	7A	Airlock, HP gas (2 O2, 2 N2) (on SLDP)
21-Jun-01	7A.1	RSRs, RSPs, ISPRs (on MPLM); SM MMOD Shields, SPP PWP, OTD (on ICC); APFRs (Sidewall) (c).
4-Jul-01	6P	Progress-M1
23-Aug-01	UF1	ISPR, RSRs, RSPs, MELFI (on MPLM)
6-Sep-01	7P	Progress-M1

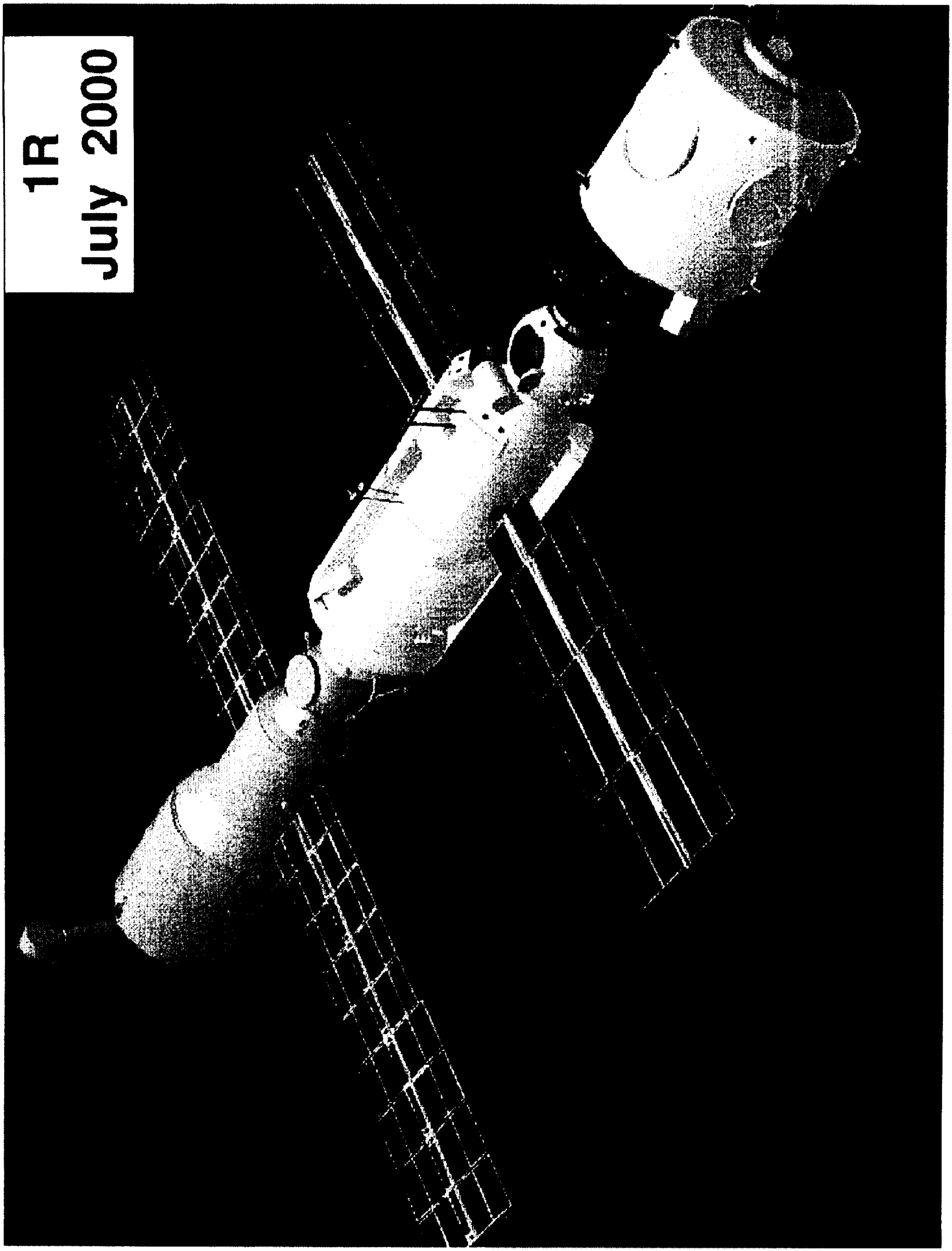
(a) - 3 Person Permanent International Human Presence Capability
(b) - Microgravity Capability
(c) - 3 ISS crew member rotation

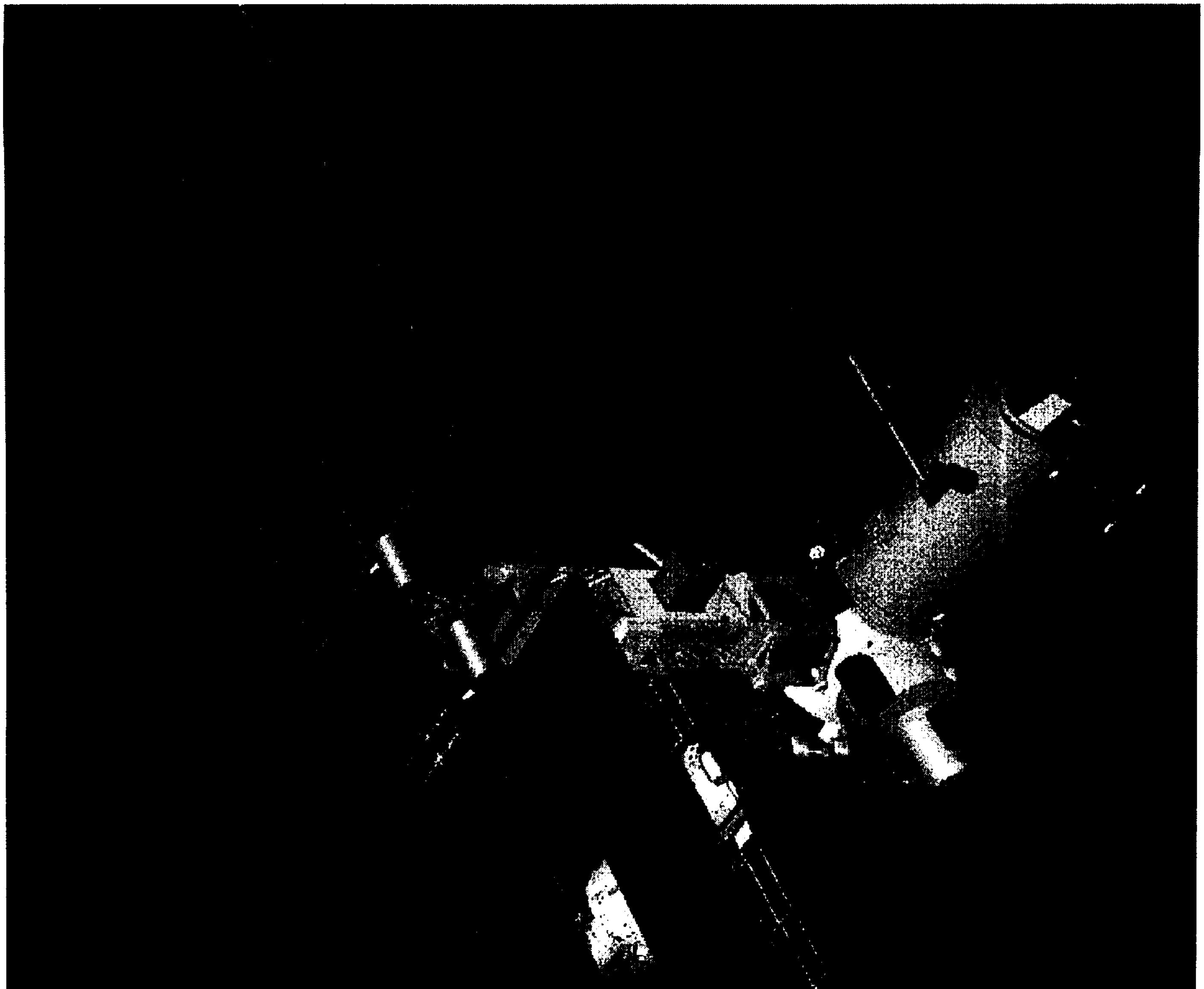
Assembly Sequence, Revision E Planning Reference
(For Planning Purposes Only, Pending Space Station Control Board Approval)
REV E/DCN 04 3/2/00

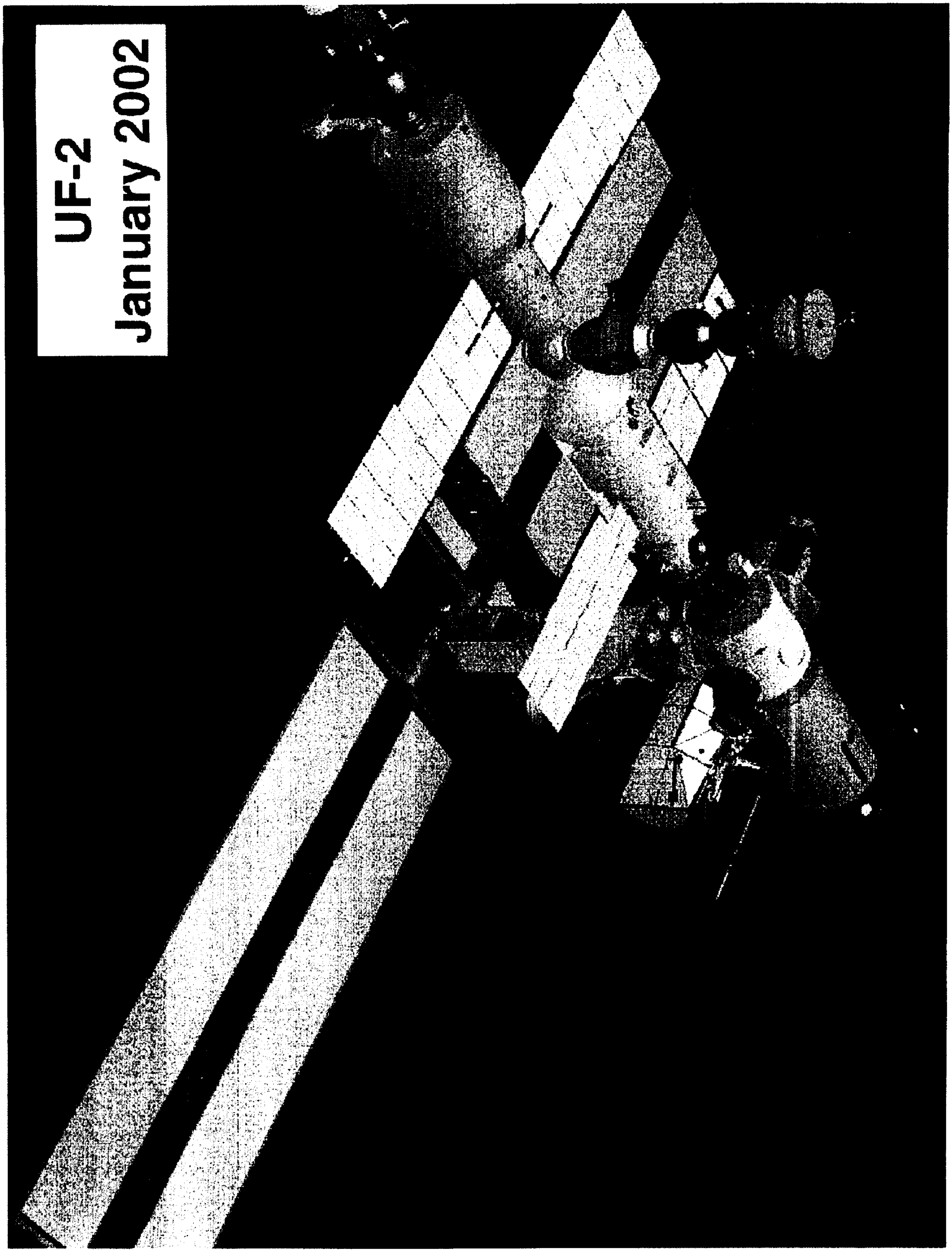
Launch Date	Flight	Delivered Elements
Oct-01	8A	S0, MT, GPS, Umbilicals, A/L Spur (c)
Oct-01	3S	3 Soyuz-TMA
Jan-02	UF2	ISPRs, RSRs, RSPs (MPLM); MBS; PDGF (Sidewalls)
Feb-02	9A	S1 (3 rads), TCS, CETA (1), S-band
Apr-02	4S	4 Soyuz-TM (c)
May-02	11A	P1 (3 rads), TCS, CETA (1), UHF
Jun-02	9A.1	Science Power Platform w/4 solar arrays and ERA
Sep-02	12A	P3/4, PV Array (4 battery sets), 2 ULCAS
Sep-02	5S	5 Soyuz-TMA (c)
Oct-02	12A.1	ISPR, RSRs, RSPs (MPLM); P5 w/Radiator OSE (c)
Jan-03	13A	S3/4, PV Array (4 battery sets), 4 PAS
TBS	3R	Universal Docking Module (UDM)
TBS	5R	Docking Compartment 2 (DC2)
Feb-03	10A	Node 2 (4 DDCU racks); NTA (on Sidewall)
Mar-03	6S	6 Soyuz-TMA
May-03	10A.1	Propulsion Module
Jun-03	1J/A	ELM PS (4 Sys, 3 ISPRs, 1 Stow); 2 SPP SA w/truss, SM MMOD Shields (ULC)
Aug-03	7S	7 Soyuz-TMA
Sep-03	1J	JEM PM (4 JEM Sys racks), JEM RMS
Oct-03	UF3	ISPRs, 1 JEM rack, RSPs (on MPLM); Express Pallet w/Payloads
Jan-04	UF4	Truss Attach Site P/L; Express Pallet w/Payloads; ATA, SPDM (SLP)
Feb-04	8S	8 Soyuz-TMA
Feb-04	2J/A	JEM EF, ELM-ES w/EF Payload, ICS, and SFA; 4 PV battery sets (on SLP)
TBS	9R	Docking & Stowage Module (DSM) (FGB module type)
May-04	14A	2 SPP SA w/truss, 4 SM MMOD Wings (ULC); Cupola (SLP); MT/CETA Port Rails (SLP)
Jun-04	UF5	ISPRs, RSPs (on MPLM); Express Pallet w/Payloads
Aug-04	9S	9 Soyuz-TMA
Sep-04	20A	Node 3 (2 Avionics, 2 ECLSS racks)
Oct-04	1E	APM (ISPRs)
TBS	8R	Research Module #1 (RM-1)
Jan-05	17A	1 Lab Sys, 4 Node 3 Sys, 2 CHeCS, RSPs, ISPRs (MPLM) - (d)
Jan-05	10S	10 Soyuz-TMA
Feb-05	18A	CRV #1, CRV adapter - (e)
Mar-05	19A	RSPs, 1 RSR, ISPRs, 4 Crew Qtrs. (on MPLM); S5 - (f)
May-05	15A	S6, PV Array (4 battery sets), Stbd MT/CETA rails
TBS	10R	Research Module #2 (RM-2)
Jun-05	UF7	Centrifuge Accommodations Module (CAM)
Jul-05	11S	11 Soyuz-TMA
Jul-05	UF6	RSPs, ISPRs (on MPLM); 2 PV battery sets (on SLP)
Sep-05	16A	Hab (5 Hab sys racks, RSRs, ISPRs) - (g)

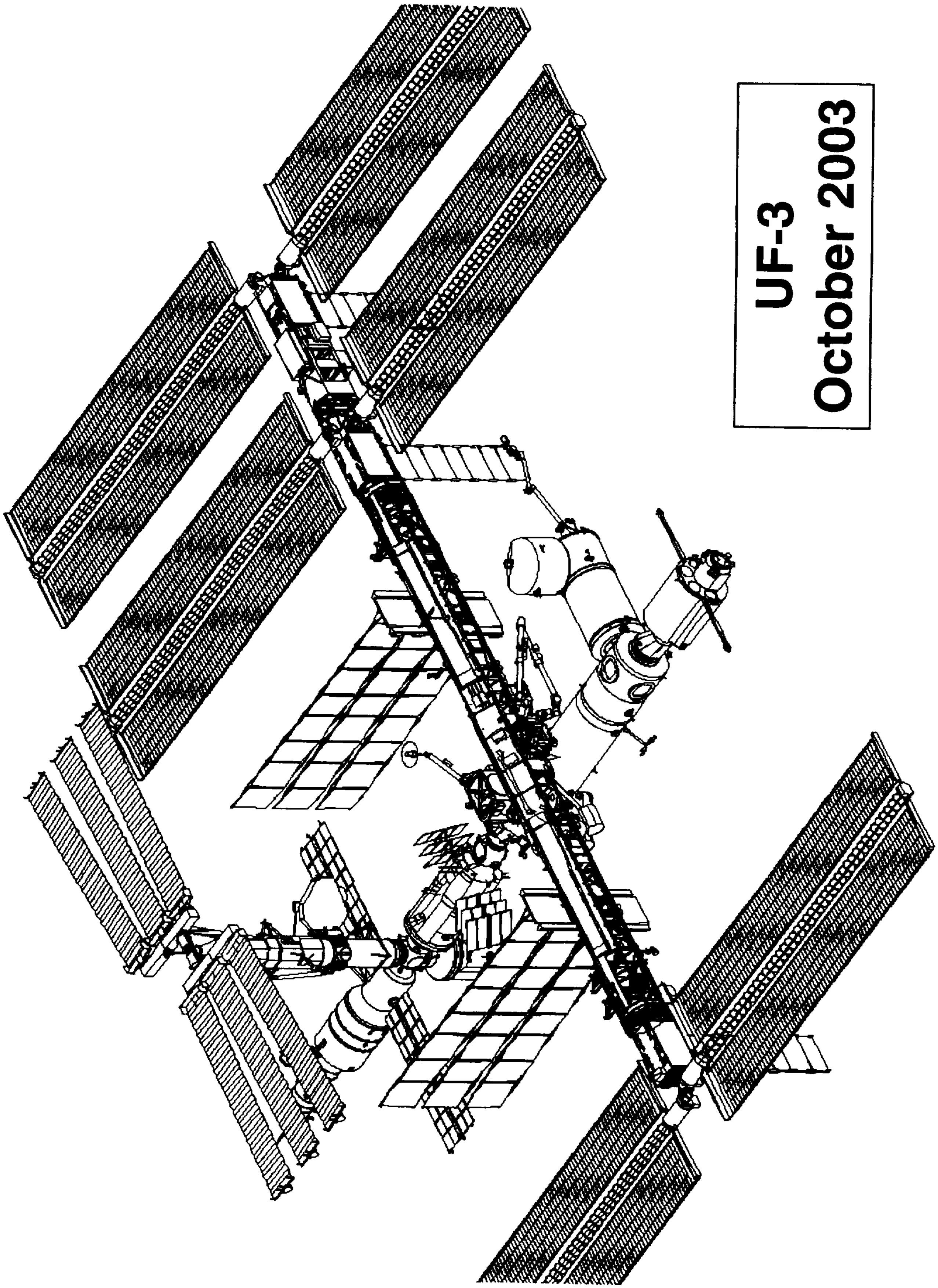
(c) - 3 ISS crew member rotation
(d) - 6 Person USOS ECLSS Capability
(e) - 6 Person Permanent International Human Presence Capability
(f) - Rack traffic assumes transition to 6 person crew on 19A.
(g) - 7 person permanent crew capability

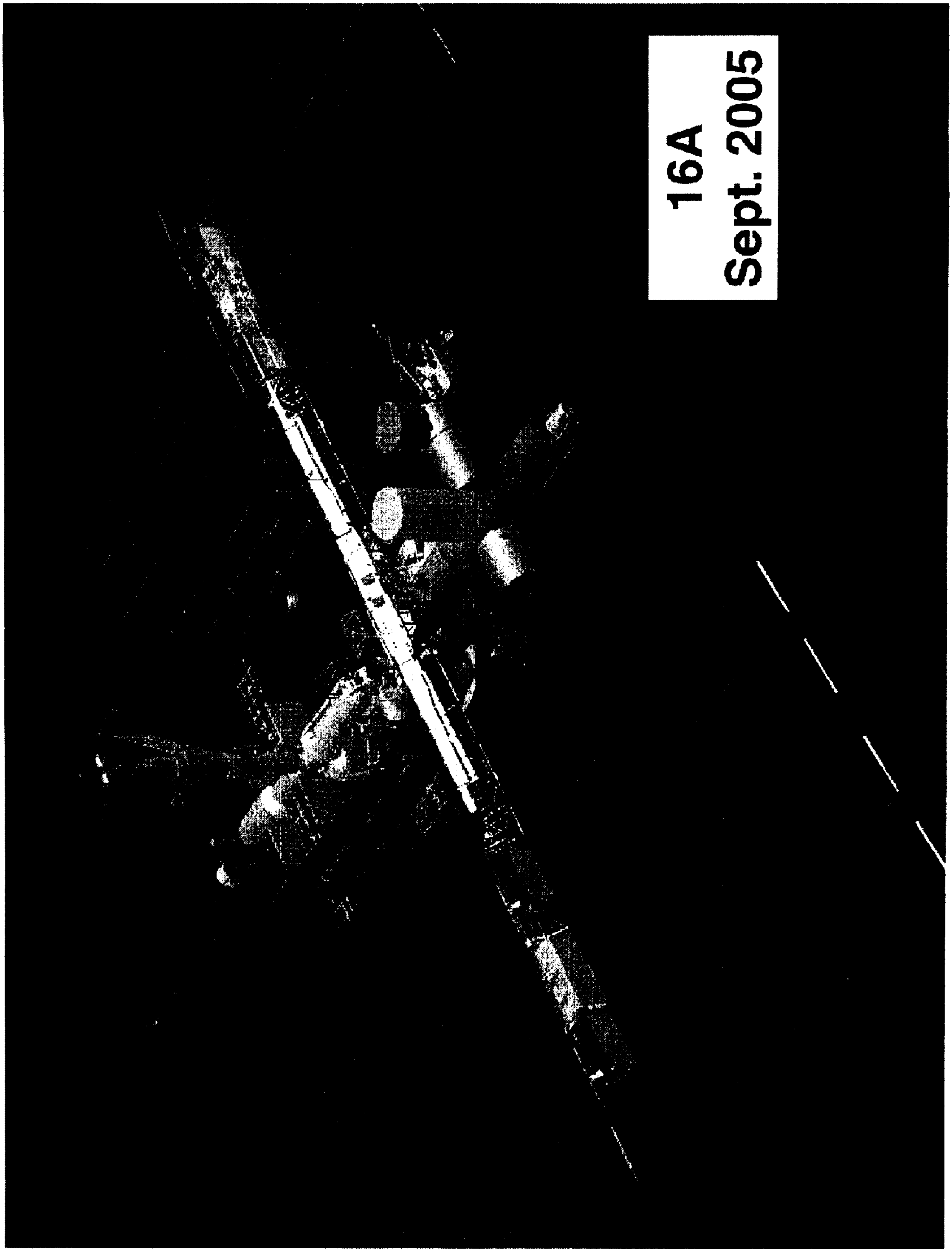

2A.2A
June 2000


1R
July 2000


UF-1
August 2001


UF-2
January 2002


UF-3
October 2003

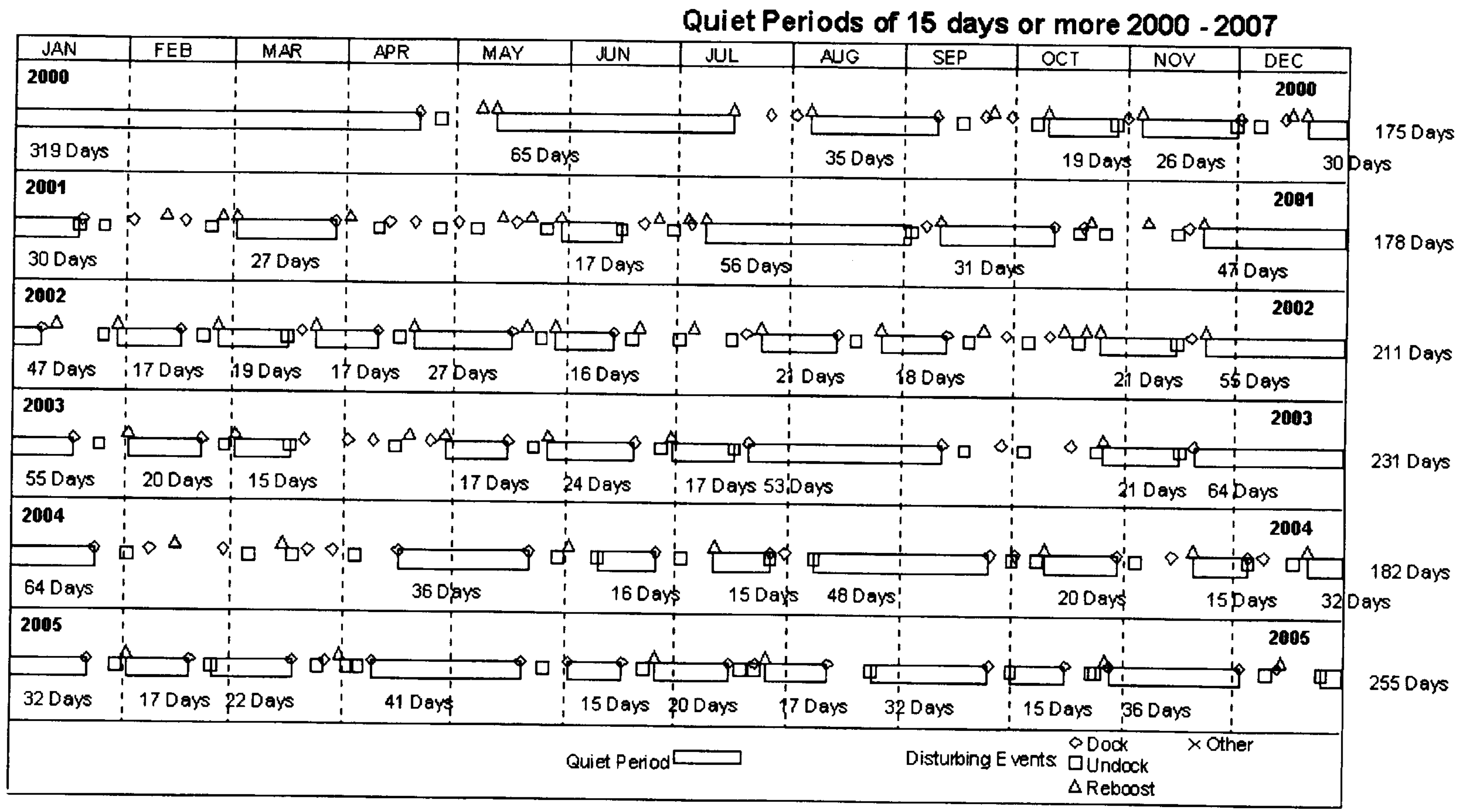

16A
Sept. 2005

Comparitive Mass Properties Of Selected Stages

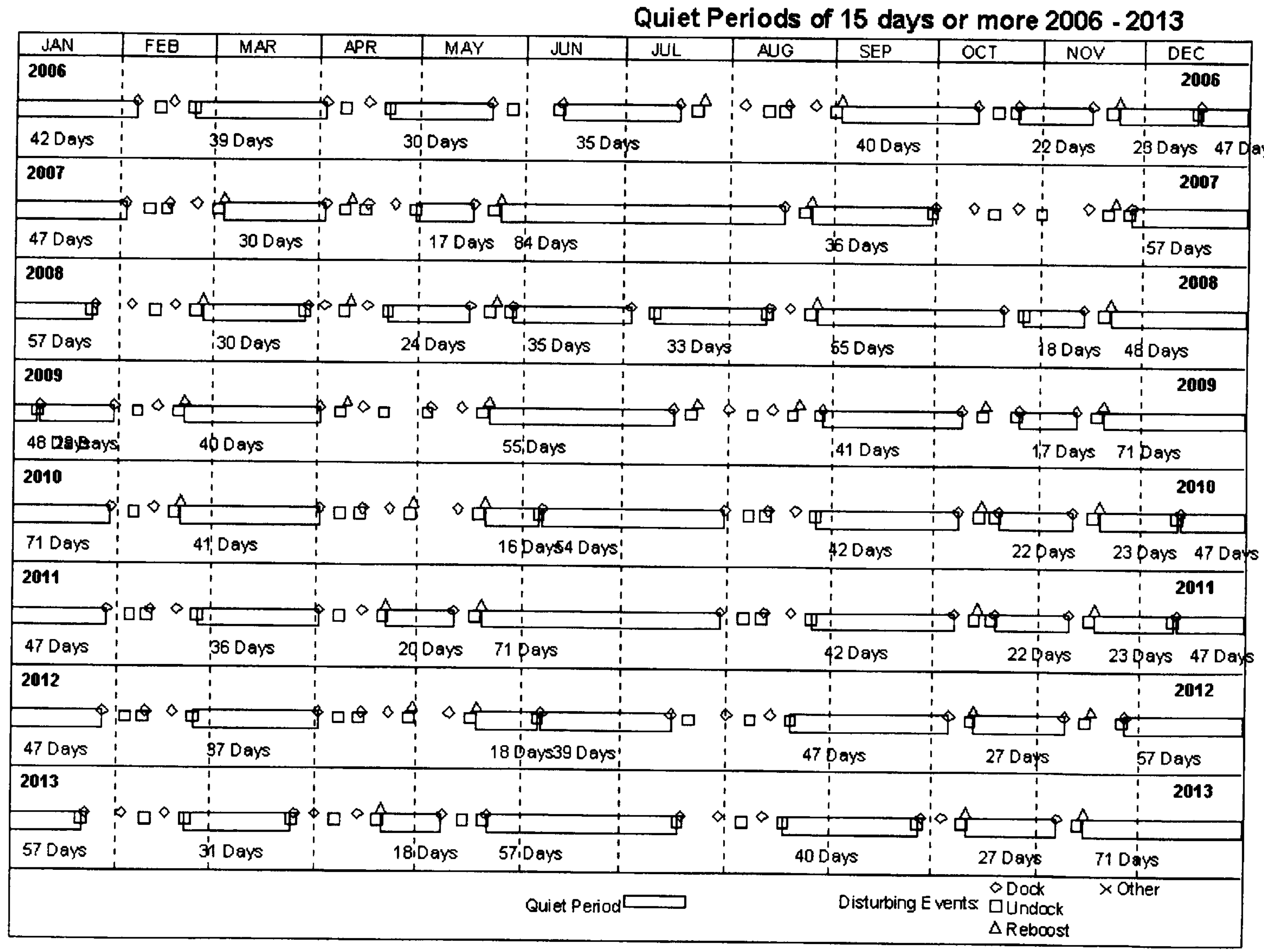
Configuration	Total Mass (lbs)	Center of Mass (ft) [x, y, z]			Principle To Body (degrees) [Roll, Pitch, Yaw]		
UF-1	297785	-40.11	0.67	9.45	1.8	-5.2	-0.6
UF-2	334292	-37.53	0.52	9.19	2.1	-7.9	-0.3
UF-3	670833	-20.73	-9.94	10.60	-0.3	-3.3	40.6
16A	1035473	-15.34	-1.28	14.87	0.1	-6.1	-8.4

Note:	U.S. Lab Node1 I/F @	x	y	z
	ESA COF Lab Node 2 I/F @	x	y	z
	NASDA JEM Lab Node 2 I/F @	x	y	z

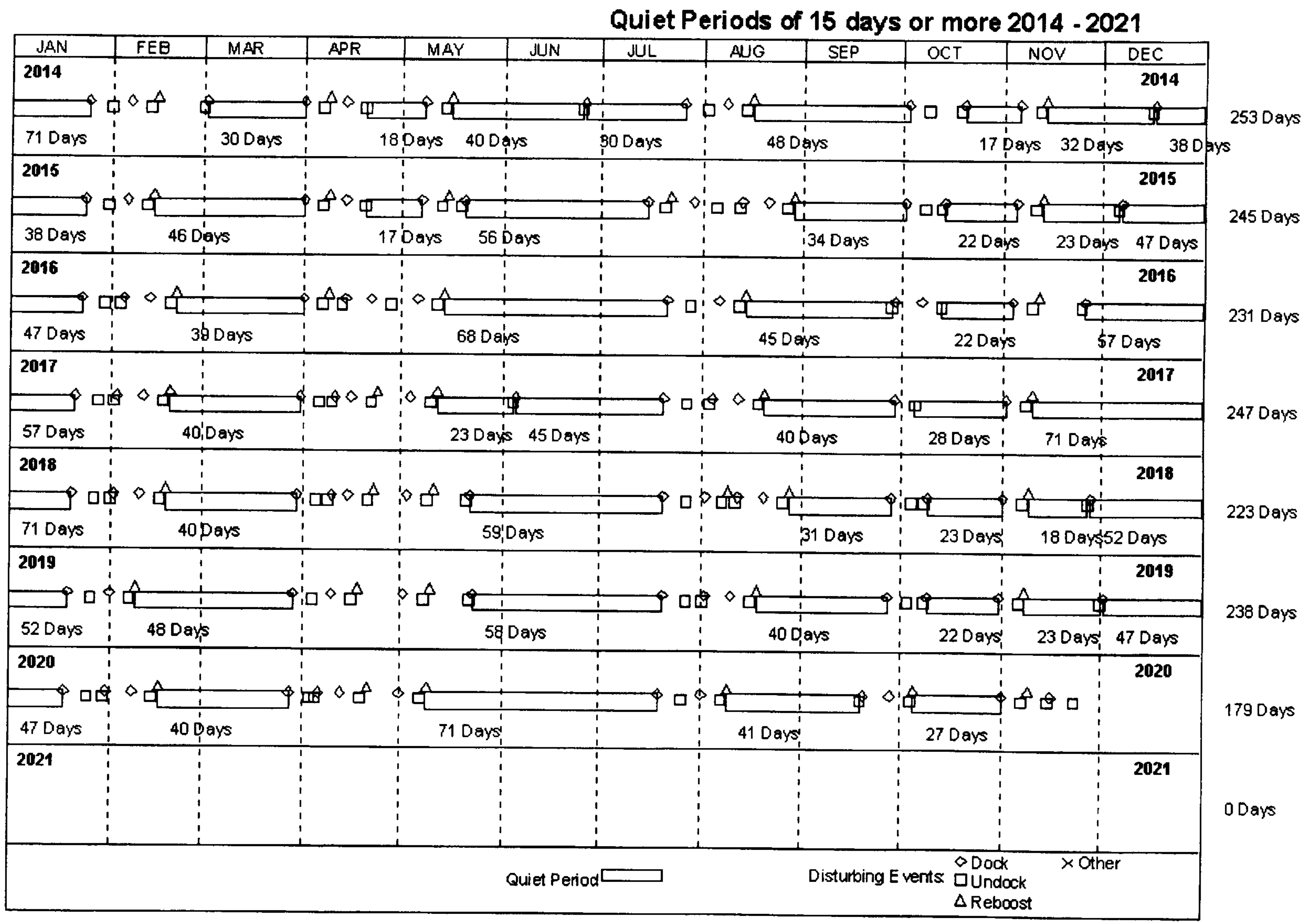
Microgravity Periods
(2000 - 2005 DAC8 Results)



Microgravity Periods
(2006 - 2019 DAC8 Results)



Microgravity Periods
(2006 - 2019 DAC8 Results Continued)



5/6/29

5125-8
22 p3

MGMG #19

20010019731

Paper Number: 16

Microgravity Emissions Laboratory facility and testing results

Anne McNelis & Thomas Goodnight
NASA Glenn Research Center
Cleveland, Ohio

Microgravity Measurements Group
July 12, 2000

Microgravity Emissions Laboratory Facility and Testing Results

Anne M. McNelis
Thomas W. Goodnight

Microgravity Emissions Laboratory

Microgravity Emissions Laboratory (MEL) is part of the Structural Dynamics Laboratory (SDL) at GRC

http://www.grc.nasa.gov/WWW/MEL

These collocated labs combine environmental, modal, and characterization work; all in one facility

Thomas Goodnight - SDL Facility Manager

216-433-2381

Thomas.W.Goodnight@grc.nasa.gov

Anne McNelis - MEL Technical Lead

216-433-8880

Anne.M.McNelis@grc.nasa.gov

Microgravity Emissions Laboratory

The goal is to provide testing support for simulation and verification of the Space Station microgravity environment

- Component and Rack surveys for ISS
- Essential for ground SEA/ FEM analytical correlation
- Essential to predicting interface and science levels on orbit

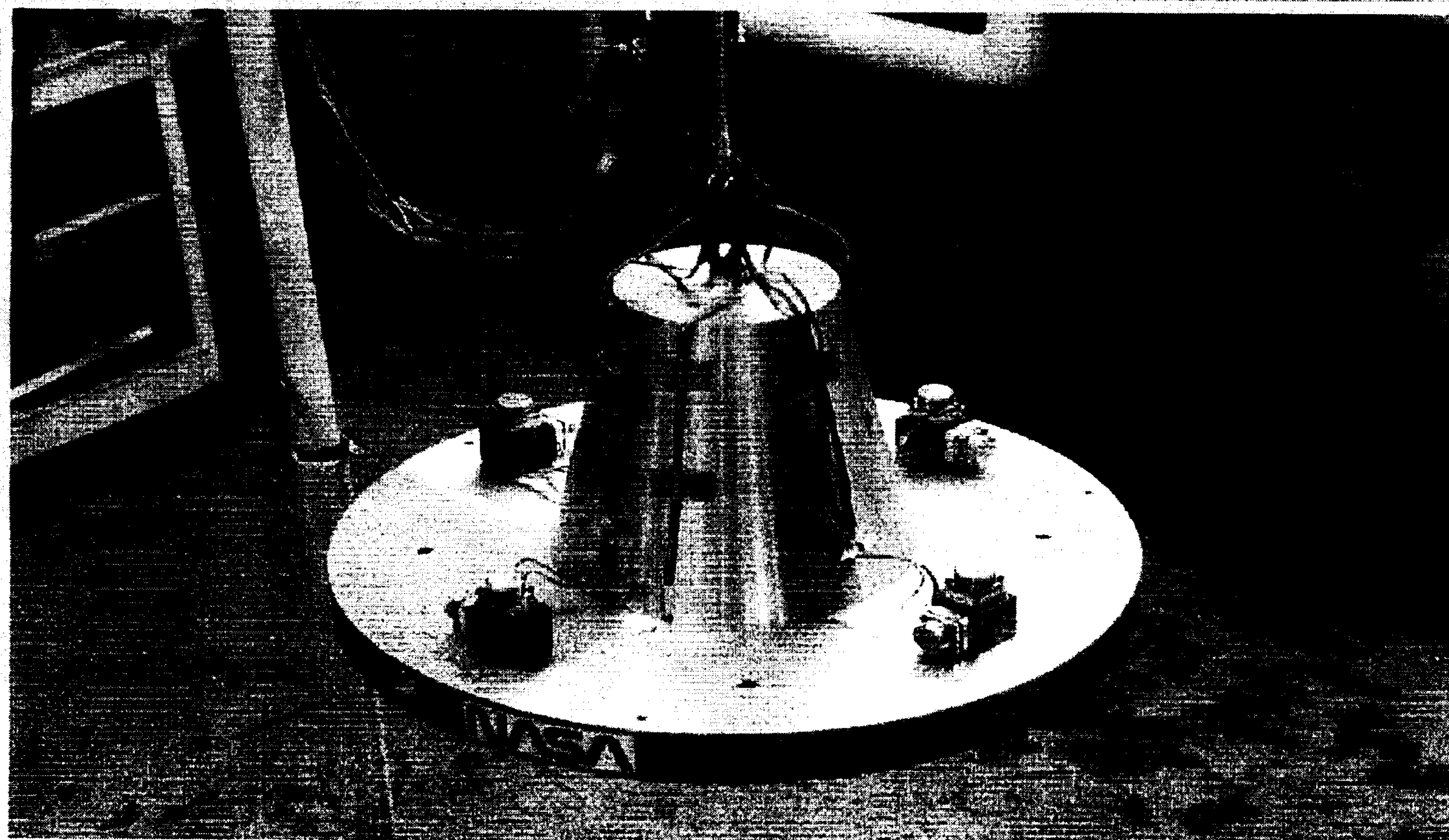
Microgravity Emissions Laboratory Capabilities

- Maximum test article -Rack level
  - 3'x 3.5' x 7' (0.9 m x 1.0 m x 2.0 m) vertical mount
  - Capable of testing payloads up to 2250 lbm (1000+ kg)
  - Separate 1050 lbm (475 kg) isolation frame to be available
  - Maximum component test article 750 lb (300 kg) with fixture
- MEL measurements targeted to characterizing disturbances down to 10^{-7} g from ~.5 Hz to 300 Hz
- Facility noise floor to be improved upon and rebaselined by October 2000

Microgravity Emissions Laboratory Scheduling

- Similar to SDL approach
    - Schedule per MEL homepage.
      http://www.grc.nasa.gov/WWW/MEL via Anne McNelis , Mark Houston or Tom Goodnight.
    - Typical lead time minimally 6 weeks to allow for non-standard fixturing.
      -Currently we have an EXPRESS double locker and soon to be available EXPRESS drawer configuration
    - Outside vendor testing done per Space Act Agreement.
    - Test Costs are per full cost accounting with a simple component test in the 5-10 K region.

Microgravity Emissions Laboratory Accelerometer Platform

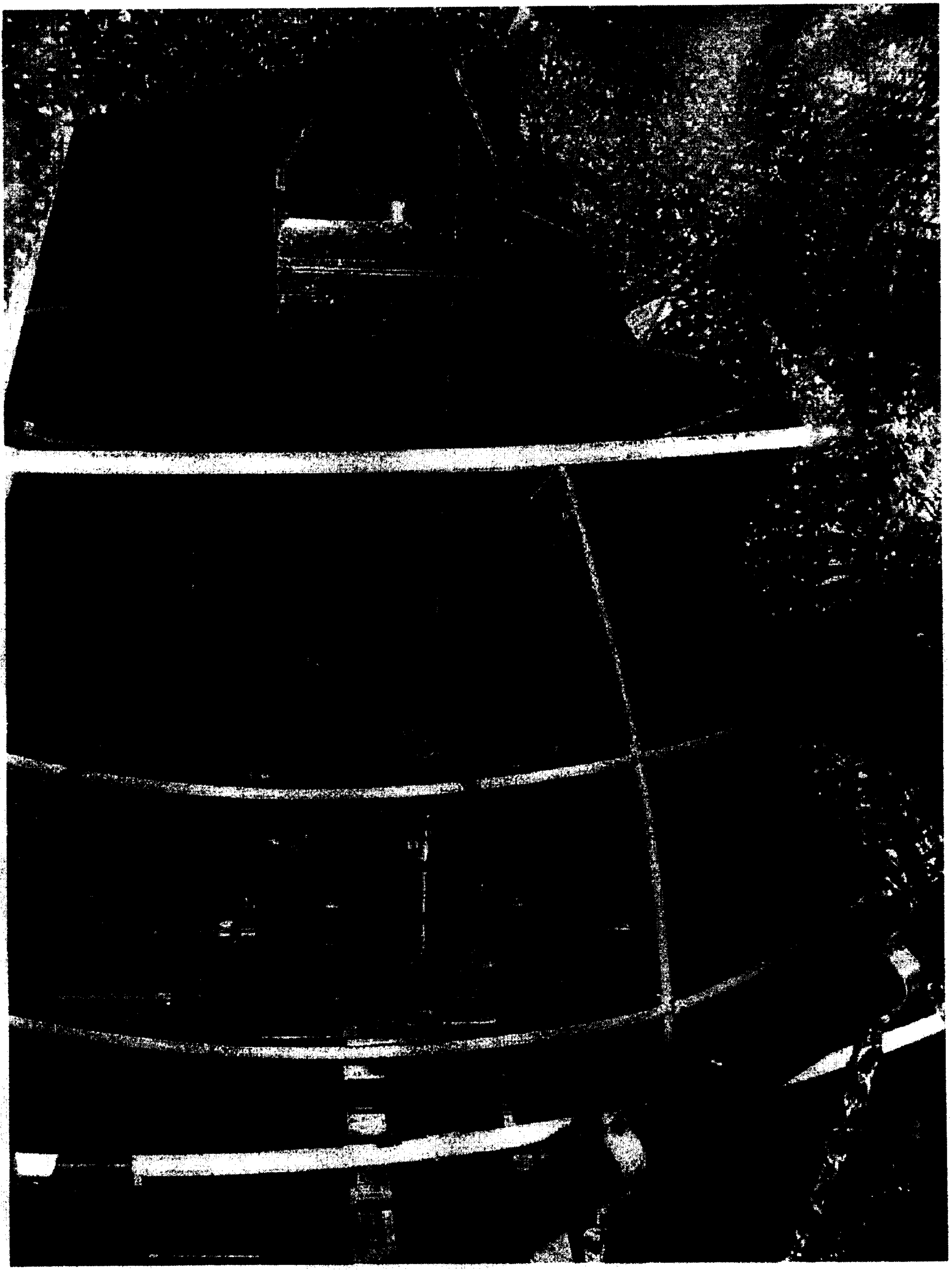


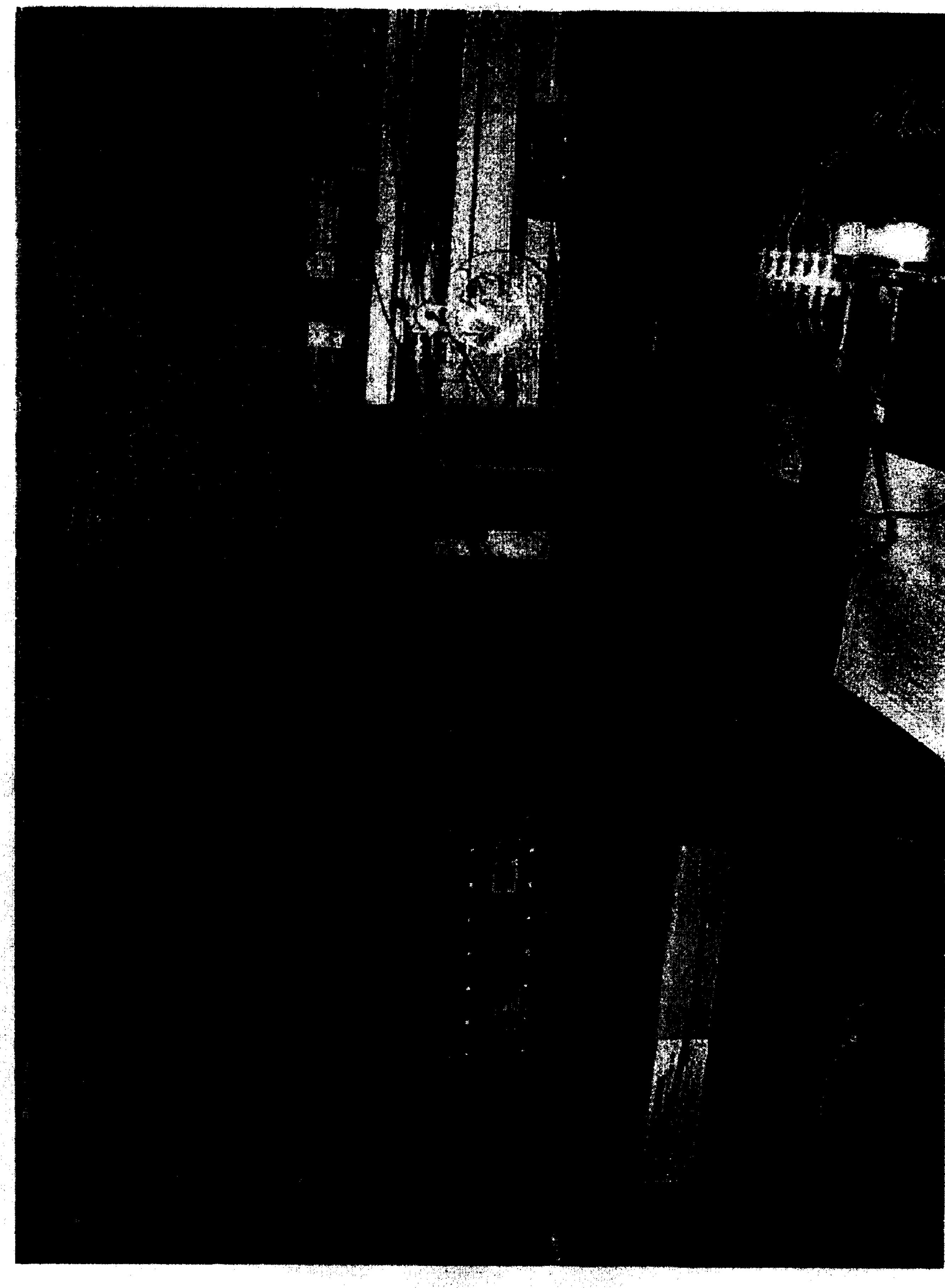
MEL Methodology

- Acquire Mass Moment of Inertia of component
- Acquire Background and Operation Emissions Acceleration Time Histories
- Compute narrowband Autospectra and FRF
- Apply frequency domain FORTRAN programs to compute rigid body forces & moments
- Compute actual narrowband and transform to 1/3 octave band forces and moments at CG of the component

Microgravity Emissions Lab Method

- F=MxA (inertial forcing function)
- The diagonal mass matrix is currently measured and can be derived from FEA data if avaliable
- The acceleration vector at the combined hardware/fixture is least squared fit from 5 biaxial pairs (10 accelerometers total)
- Direct interface/science accelerations not currently made
- MEL inertial forcing functions are input to the assessment of the compliance of the ug allocation





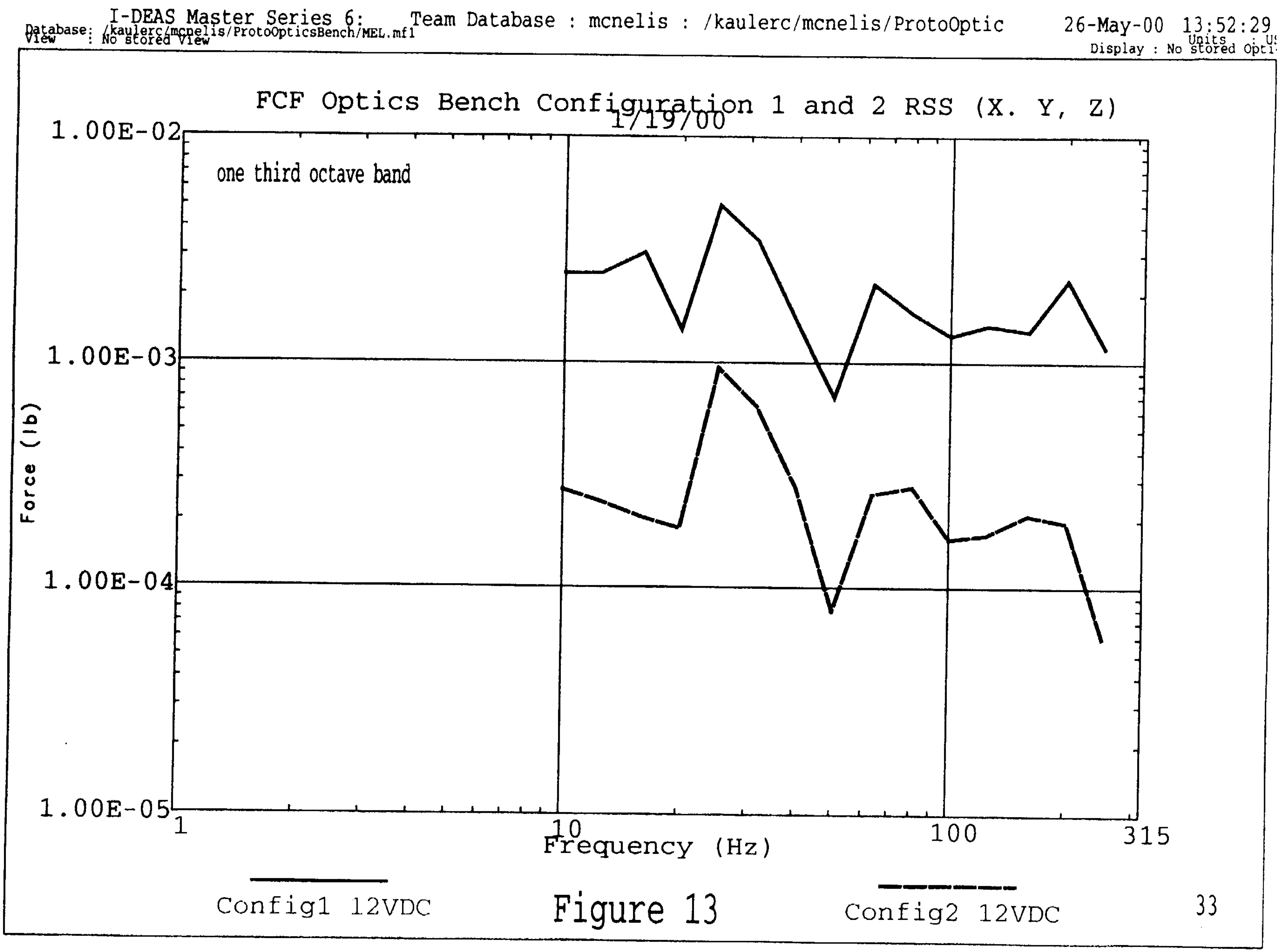
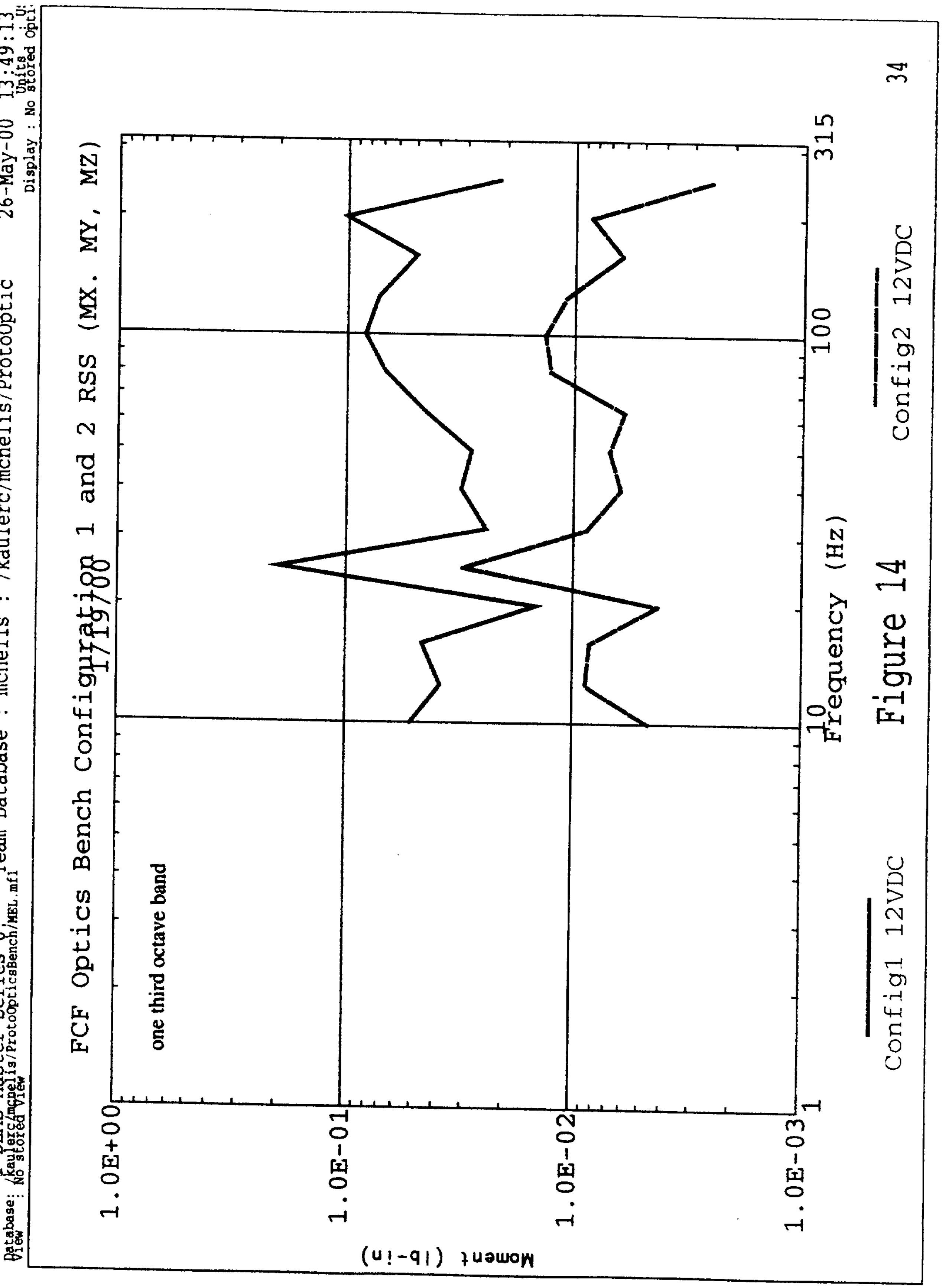

I-DEAS Master Series 6: Team Database : mcnelis : /kaulerc/mcnelis/ProtoOptic
26-May-00 13:52:29
Database: /kaulerc/mcnelis/ProtoOpticsBench/MEL.mf1
View : No stored View
Display : No stored Opti
FCF Optics Bench Configuration 1 and 2 RSS (X. Y, Z)
1/19/00
one third octave band
Force (lb)
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1
10
100
315
Frequency (Hz)
Config1 12VDC
Config2 12VDC
33

Figure 13


I-DEAS Master Series 6: Team Database : mcnelis : /kaulerc/mcnelis/ProtoOptic 26-May-00 13:49:13
Database: /kaulerc/mcnelis/ProtoOpticsBench/MEL.mf1
View : No stored View
Units
Display : No stored Opti
FCF Optics Bench Configuration 1 and 2 RSS (MX. MY, MZ)
1/19/00
one third octave band
Moment (lb-in)
1.0E+00
1.0E-01
1.0E-02
1.0E-03
1
10
100
315
Frequency (Hz)
Config1 12VDC
Config2 12VDC
34
Figure 14

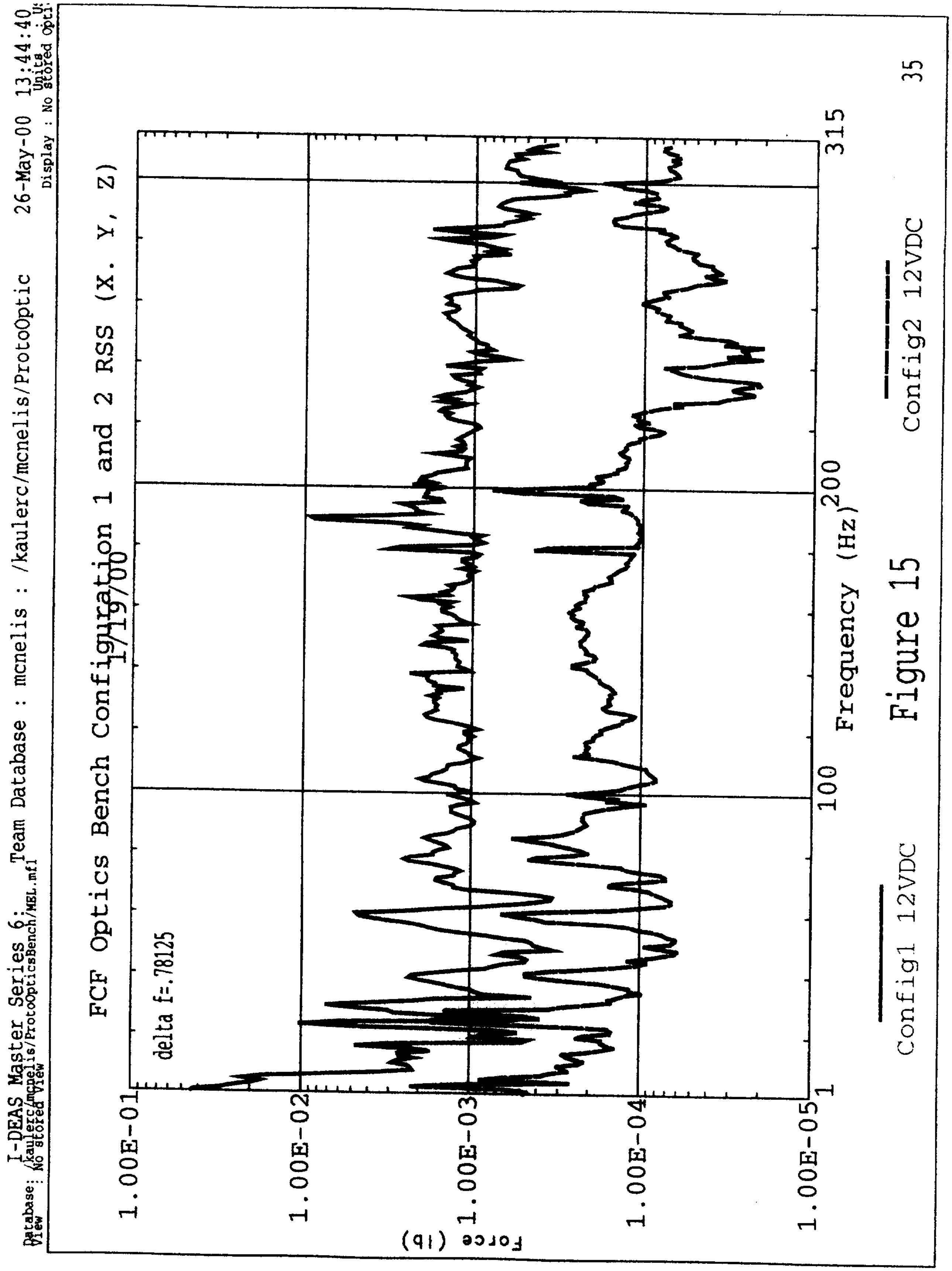

I-DEAS Master Series 6: Team Database : mcnelis : /kaulerc/mcnelis/ProtoOptic 26-May-00 13:44:40
Database: /kaulerc/mcnelis/ProtoOpticsBench/MBL.mf1
View : No stored View
Display : No stored Optio
FCF Optics Bench Configuration 1 and 2 RSS (X. Y, Z)
1/19/00
delta f=.78125
1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
Force (lb)
1
100
200
315
Frequency (Hz)
Config1 12VDC
Config2 12VDC
35

Figure 15

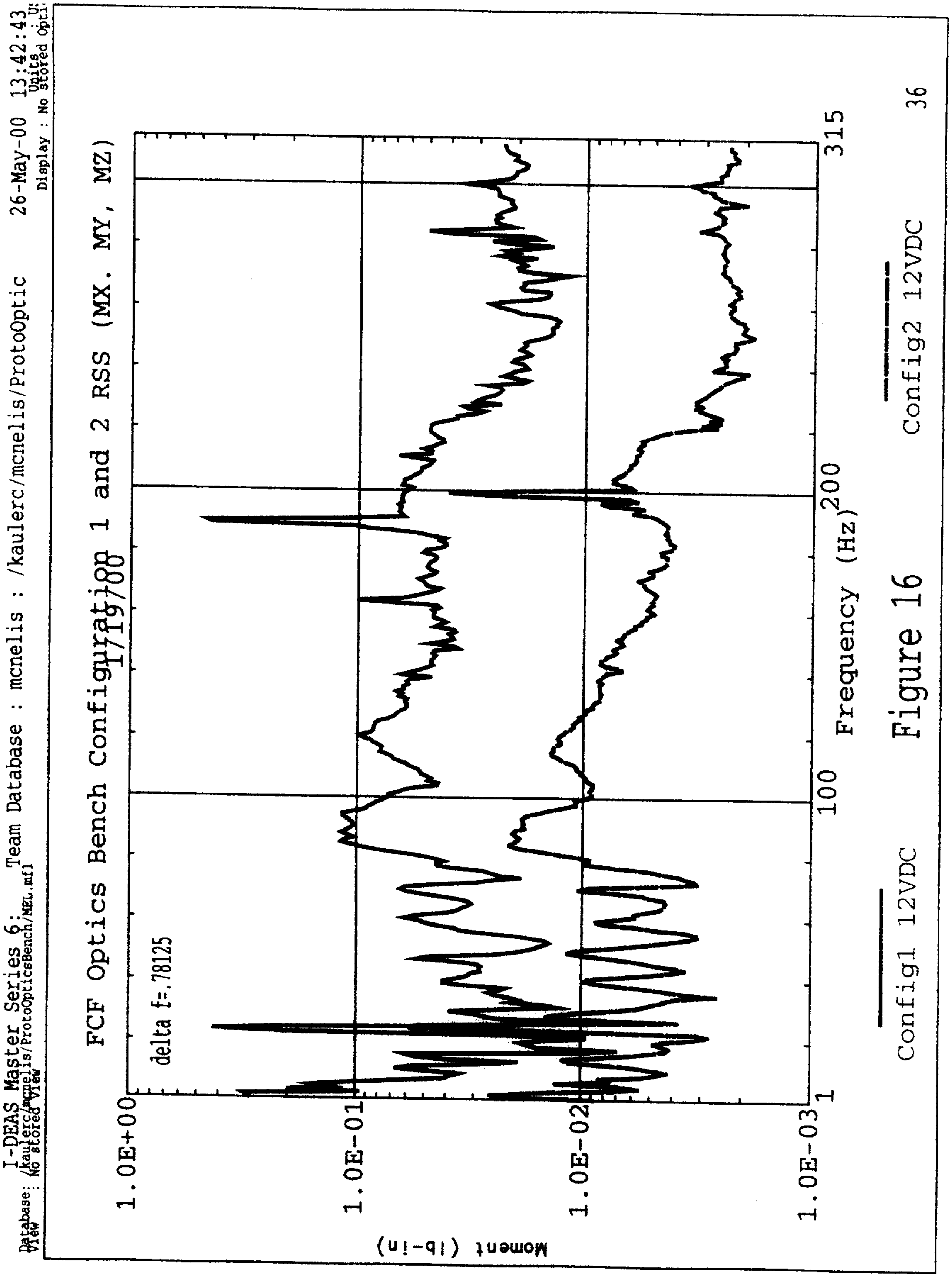
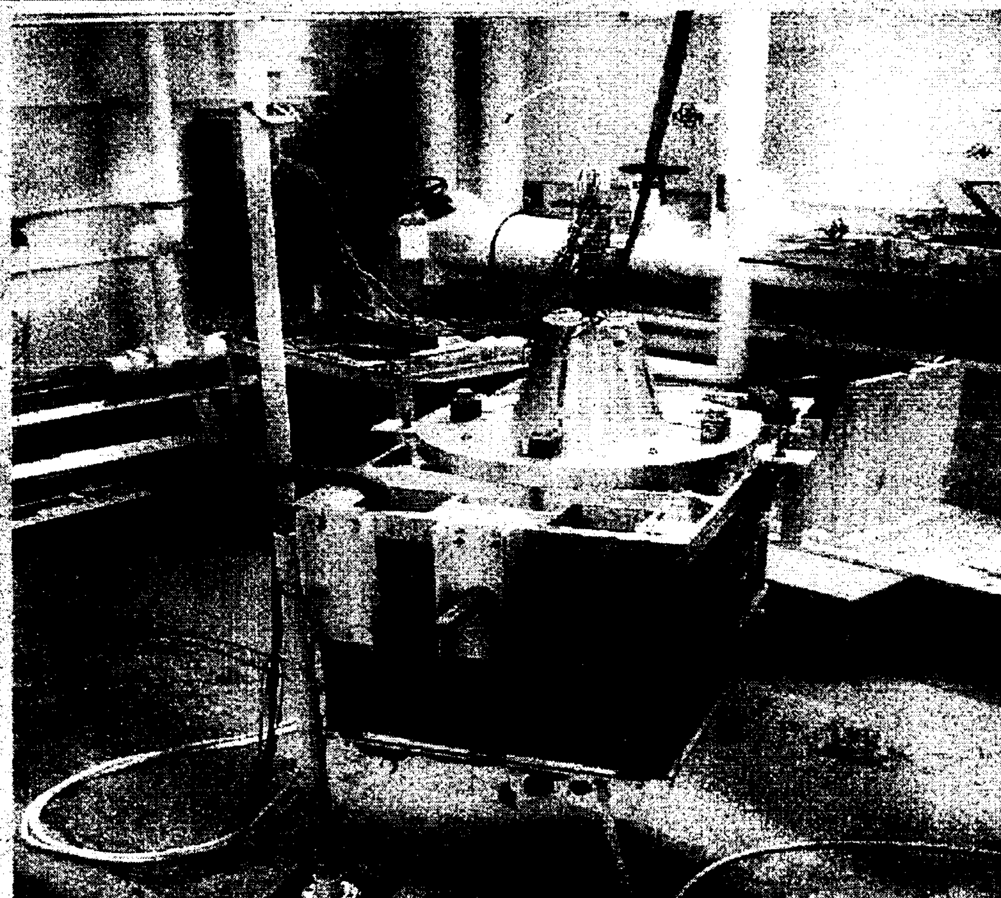

I-DEAS Master Series 6: Team Database : mcnelis : /kaulerc/mcnelis/ProtoOptic 26-May-00 13:42:43
Database: /kaulerc/mcnelis/ProtoOpticsBench/MEL.mf1
View : No stored View
Units : US
Display : No stored Optic
FCF Optics Bench Configuration 1 and 2 RSS (MX, MY, MZ)
1/19/00
delta f=.78125
Moment (lb-in)
1.0E+00
1.0E-01
1.0E-02
1.0E-03
1
100
200
315
Frequency (Hz)
Config1 12VDC
Config2 12VDC
36

Figure 16

MEL Tests to Date

- SAMS Tape Drive (Sept 99)
- FCF Single Fan Test (Nov 99)
- FCF Stereolith Optics Bench (Jan 00)
- ugSEG (February 00)
- FCF Stereolith Optics Bench with pseudo-package configuration (Feb 00)
- PCS (May 00)
- MEL platform forcing function evaluation test (10+ Hz)

Microgravity Emissions Laboratory PCS Test



Microgravity Emissions Laboratory Future Plans

- Rack-level development testing to be done in the SDL/MEL component facility.
- Eventually to be located in the newly developed GRC Acoustical Testing Laboratory /Power Systems Facility (333-FCF Development Center) with operational Space Station Services attached.

MEL Future Signal Improvement

- Acoustical Enclosure to stabilize environment
- Transient Event Processing Scheme to develop transient forcing functions
- Implementation of CSA pneumatic units to allow full-level Rack testing with inertial fixture
- Improve acquisition of mass moment of inertia through simpler mechanical means

Future Work

- Stirling Engine Aug 00
- SAMS Drawer RTS ,ICU Aug,Oct 00

Conclusions

- MEL facility is operational and reporting process is being standardized
- Facility limitations are being explored
  - Signal noise floor improvement
  - Facility modal response
  - Environmental Control
  - 1/3 octave band resolution below 10 Hz being investigated
- Transient processing is crucial to success for “noisy” payloads
- Rack payload fixture under development

2001019133 519579 21PS

517/29

MGMG #19

Paper Number: 17

g–LIMIT status briefing

Mark S. Whorton
NASA Marshall Space Flight Center
Huntsville, Alabama

For many microgravity science experiments in the International Space Station, the ambient acceleration environment will be exceed desirable levels. To provide a more quiescent acceleration environment to the microgravity payloads, a vibration isolation system named g–LIMIT (GLovebox Integrated Microgravity Isolation Technology) is being designed. g-LIMIT is a sub-rack level isolation system that can be tailored to a variety of applications. Scheduled for launch on the UF-1 mission, the initial implementation of g-LIMIT will be a Characterization Test in the Microgravity Science Glovebox (MSG). g-LIMIT will be available to glovebox investigators immediately after characterization testing. Standard MSG structural and umbilical interfaces will be used so that the isolation mount is transparent to the user with no additional accommodation requirements. g-–LIMIT consists of three integrated isolator modules, each of which is comprised of a dual axis actuator, two axes of acceleration sensing, two axes of position sensing, control electronics, and data transmission capabilities in a minimum-volume package. In addition, this system provides the unique capability for measuring absolute acceleration of the experiment independent of accelerometers as a by-product of the control system and will have the capability of generating pristine accelerations to enhance experiment operations.

g-LIMIT Status Briefing

Dr. Mark Whorton
g-LIMIT Principal Investigator
NASA Marshall Space Flight Center

Brad T. Perkins
g-LIMIT System Engineer
NASA Marshall Space Flight Center

19th Microgravity Measurements Group Meeting
July 13, 2000
Cleveland, Ohio

National Aeronautics and Space Administration
Marshall Space Flight Center

g-LIMIT

Microgravity Science & Applications Department

- g-LIMIT - Glovebox Integrated Microgravity Isolation Technology
- g-LIMIT is a sub-rack level vibration isolation device to be used in the Microgravity Science Glovebox (MSG) on-board the ISS
- g-LIMIT is the next generation of the technology demonstrated by STABLE (USML-2, 1995)
- g-LIMIT is less than $500K payload, implemented to help achieve early microgravity science prior to ISS Assembly Complete
- Scheduled for launch on UF-1, August 01 (Rev E Assembly Schedule)

Brad Perkins, 6/29/00

National Aeronautics and Space Administration
Marshall Space Flight Center

g-LIMIT Project Milestones

Microgravity Science & Applications Department

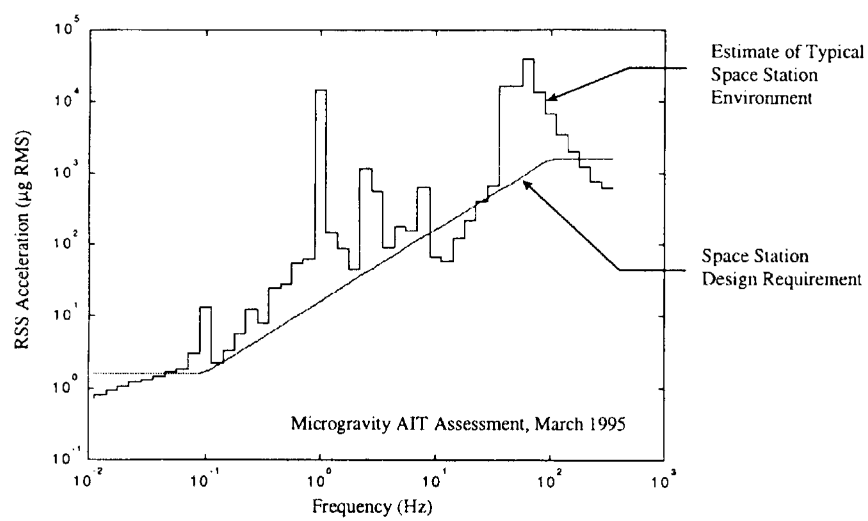
- Dr. Whorton was selected under 1996 Solicitation for Glovebox Investigations
- Funds made available February 1997 - $300K
- MSFC PMC - June 1997
- g-LIMIT PR1 - July 1997
- GI Status review held with NASA HQ - July 1997
- Authority to Proceed (ATP) - December 1997
- PR2 - March - April 1999
- For FY00 total funds- $ 95K
- PR3 Kickoff November 3, 1999
- PR3 Preboard December 10, 1999
- PR4 Kickoff June 6, 2000 (hardware delta-CDR and software CDR)
- PR4 Preboard June 30, 2000
- g-LIMIT scheduled for launch on UF-1, August 2001 (Rev E Manifest)

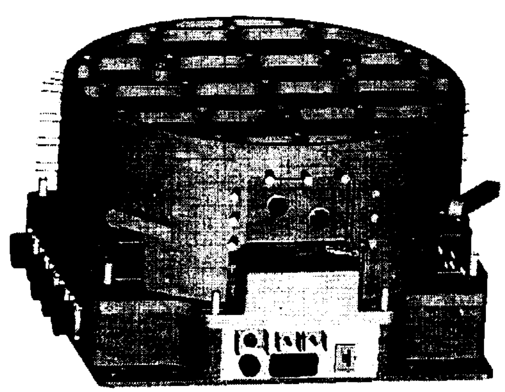
Brad Perkins, 6/29/00

National Aeronautics and Space Administration
Marshall Space Flight Center

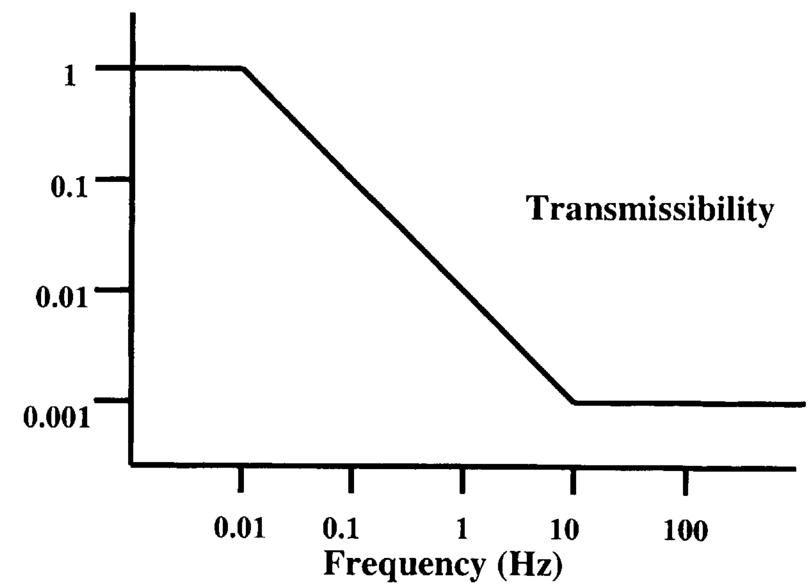
Why is Vibration Isolation Necessary for ISS?

Microgravity Science & Applications Department





G-LIMIT is a microgravity vibration isolation system for the MSG



Characterization Test Data Management

- Characterization data for each test will be archived on orbit
  - PCMCIA Flash Disk used for mass data storage
  - Requires periodic crew change-out
  - A log file will be created for each test
  - Real-time low rate data displayed on crew laptop and downlinked via 1553
  - Daily archival data downlink via medium rate telemetry
  - Two sample rates implemented:
    - Major frame sampled at 500 kHz, 8 pole filter at 125 Hz
    - Minor frame sampled at 25 Hz, 4 filter poles at 6.25 Hz

Brad Perkins, 6/29/00

Characterization Test Plan

Test No.	Test	Description	Duration (hh:mm:ss)	Data (MB)
1	Position Control Test	Position stability; bias estimation	00:10:00	1.74
2	Umbilical Stiffness Test	Estimate umbilical stiffness	00:22:00	3.83
3	Range Test	Measure range of travel	00:13:00	2.62
4	Mass & Inertia Test	Estimate mass properties	00:13:00	2.62
5	Recovery Test	Verify anti-bump function	00:06:00	1.04
6	Acceleration Control Test	stability of accel control	00:01:30	6.05
7	Quiescent Isolation Test	Isolation performance	01:10:00	282.45
8	Disturbance Rejection Test	Disturbance rejection performance	00:45:00	92.48
9	Forced Response Test	Pristine excitation performance	00:20:00	41.10
10	MSG Isolation Test	MSG induced disturbance rejection	01:45:00	92.48
11	Quasi-steady Acceleration Test	Estimation of quasi-steady acceleration	15:00:00	156.60

National Aeronautics and Space Administration
Marshall Space Flight Center

Characterization Test Plan

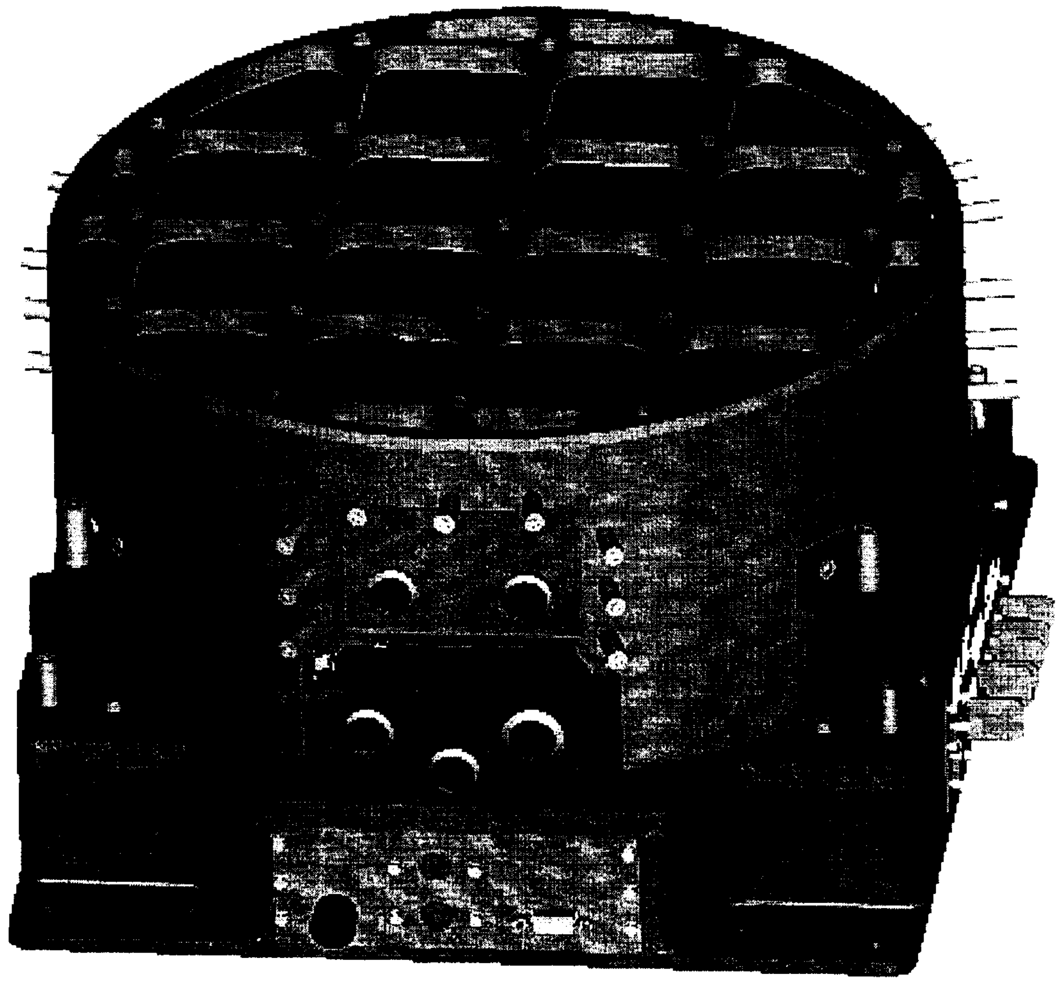
Microgravity Science & Applications Department

Day	Data Archived (MB)	Total Execution Time
1	308.68	04:13:00
2	400.74	03:15:00
3	277.44	02:15:00
4	411.02	03:20:00
5	156.6	15:00:00
6	411.02	03:20:00
7	277.44	03:15:00
8	400.74	03:15:00
9	411.02	03:20:00
10	411.02	03:20:00
11	411.02	03:20:00
12	411.02	03:20:00
13	411.02	03:20:00
14	411.02	03:20:00
15	411.02	03:20:00
Total	**5520.82**	**61:13:00**

- 15 Days of Training
- 5 Hours Run Time per Day
- 5.5 GB Data Collected (Total)

Brad Perkins, 6/29/00

g-LIMIT System
Collapsed Front View

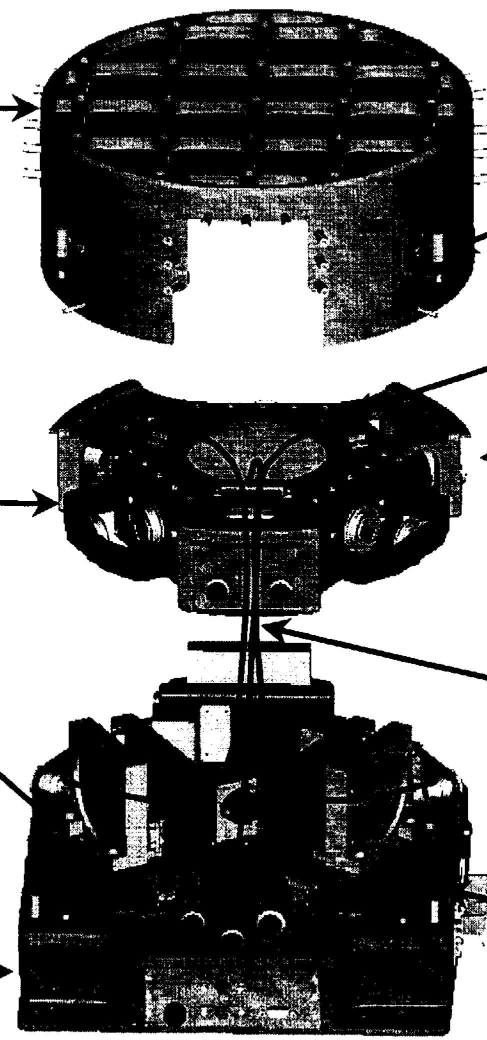


Brad Perkins, 6/29/00

National Aeronautics and Space Administration
Marshall Space Flight Center

g-LIMIT System Assembly

Microgravity Science & Applications Department



Payload Mounting Structure (PMS)

Lockdown Fasteners (3)

UIP Connector (3) Locations

Umbilical Interface Plate (UIP)

Isolator Module (IM)
- Platform subsystem (TASC*)
- Base subsystem (IM-Base)
- 3 units

* Two-axis Accelerometer Signal Conditioning (TASC)

Umbilicals

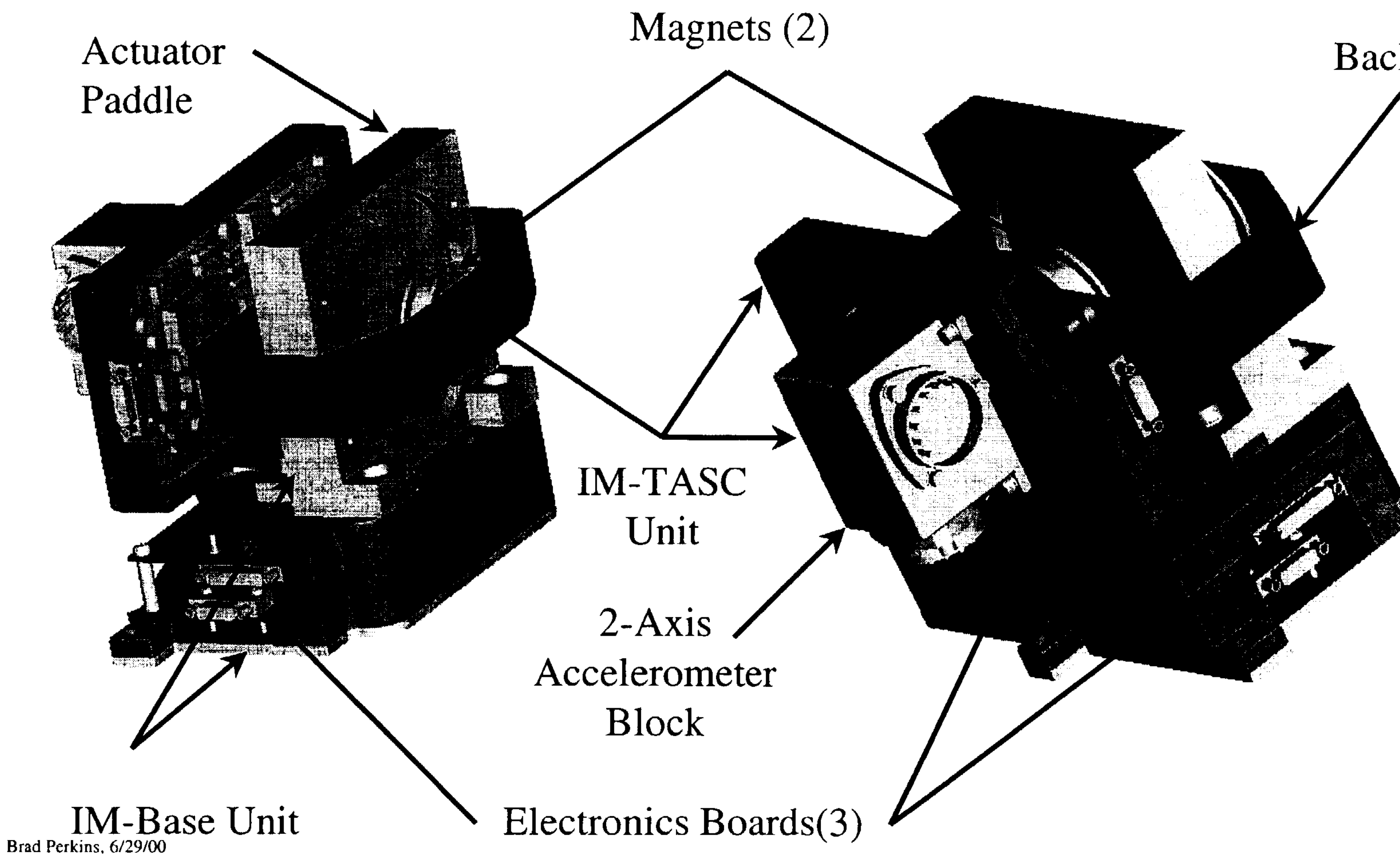
Power & Information Processor (PIP)

Bumpers (3)

National Aeronautics and Space Administration
Marshall Space Flight Center

Isolation Module (IM)

Microgravity Science & Applications Department



g-LIMIT Flight Projects

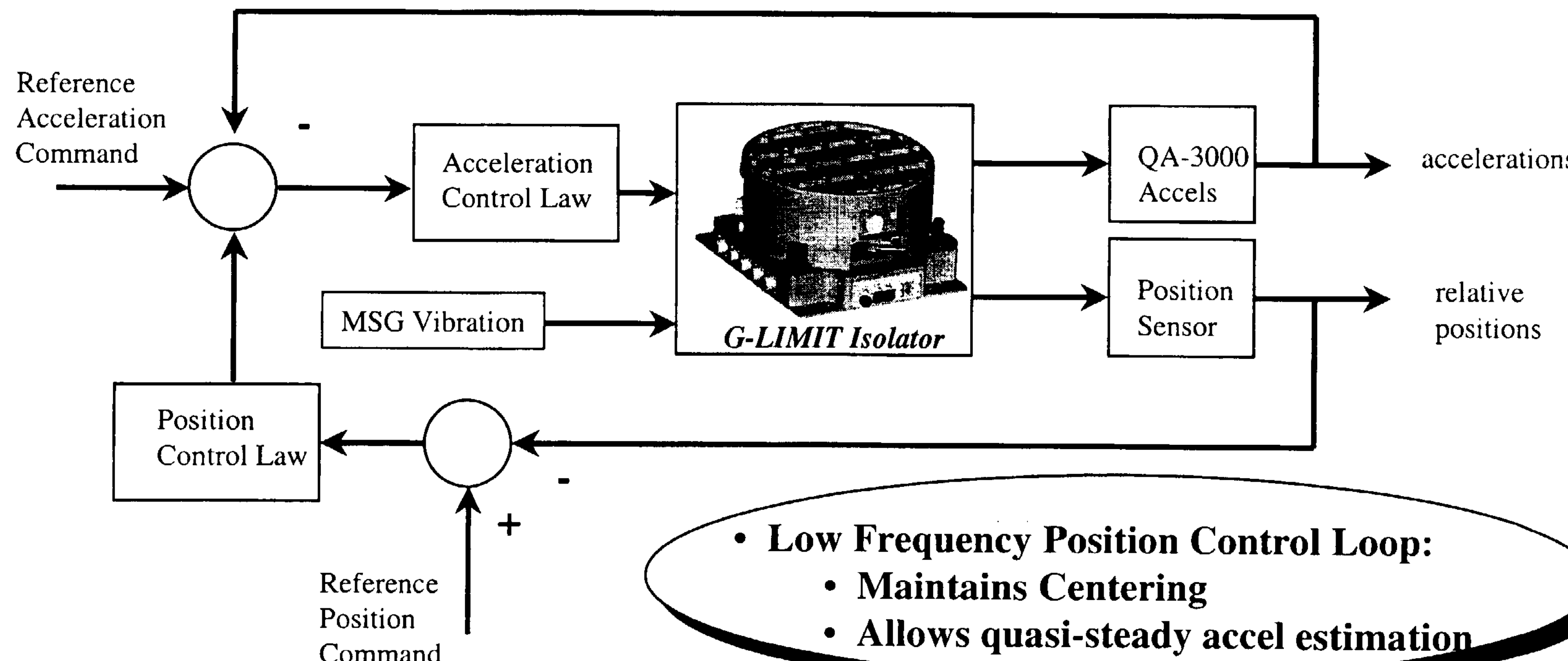
- Planned Phased Approach:
  - g-LIMIT Phase One: Hardware and software utilized for Characterization Tests
  - g-LIMIT Phase Two: Characterization Test hardware used with enhanced software
  - g-LIMIT Phase Three: Hardware and software upgrades for extended duration payload support

Brad Perkins, 6/29/00

6-DOF performance analysis

How Does g-LIMIT Isolate from Vibrations?

- High Frequency Acceleration Control Loop:
  - Cancels Inertial Motion of the Platform
  - Allows "Good Vibrations"



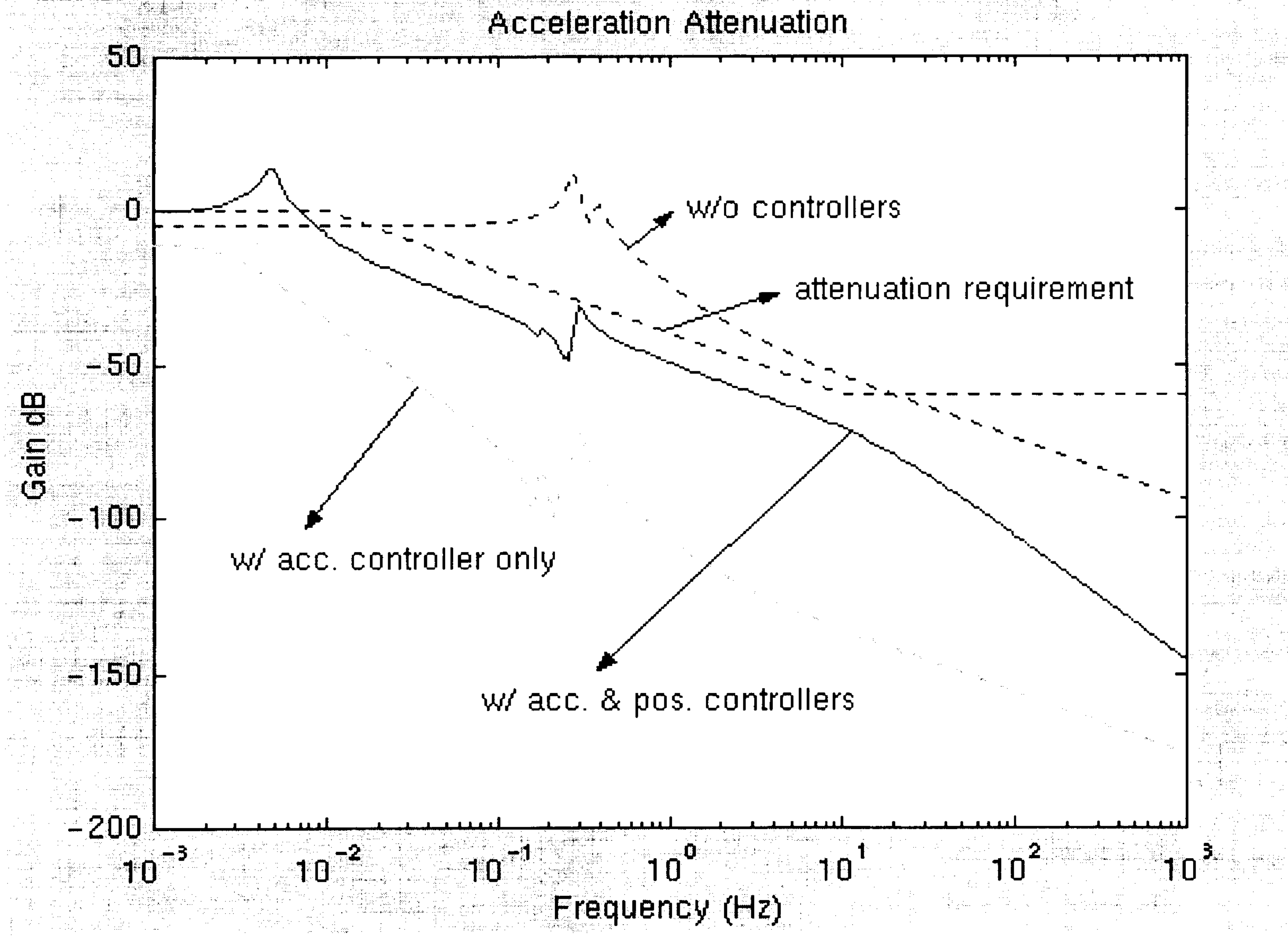
- Low Frequency Position Control Loop:
  - Maintains Centering
  - Allows quasi-steady accel estimation

Brad Perkins, 6/29/00

National Aeronautics and Space Administration
Marshall Space Flight Center

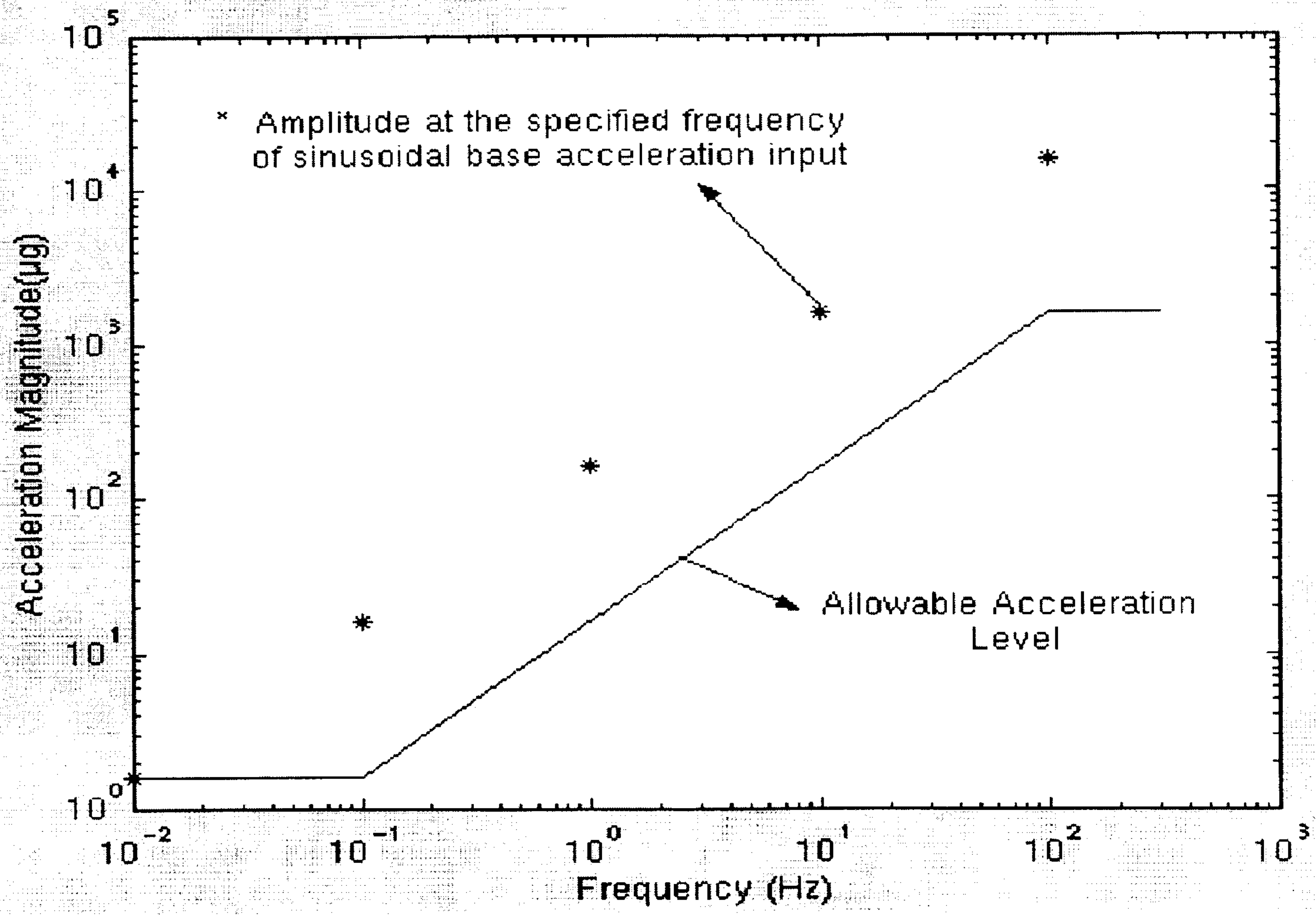
Baseline SISO Controllers

Microgravity Science & Applications Department



X-axis

Base Acceleration for Time Response Analysis

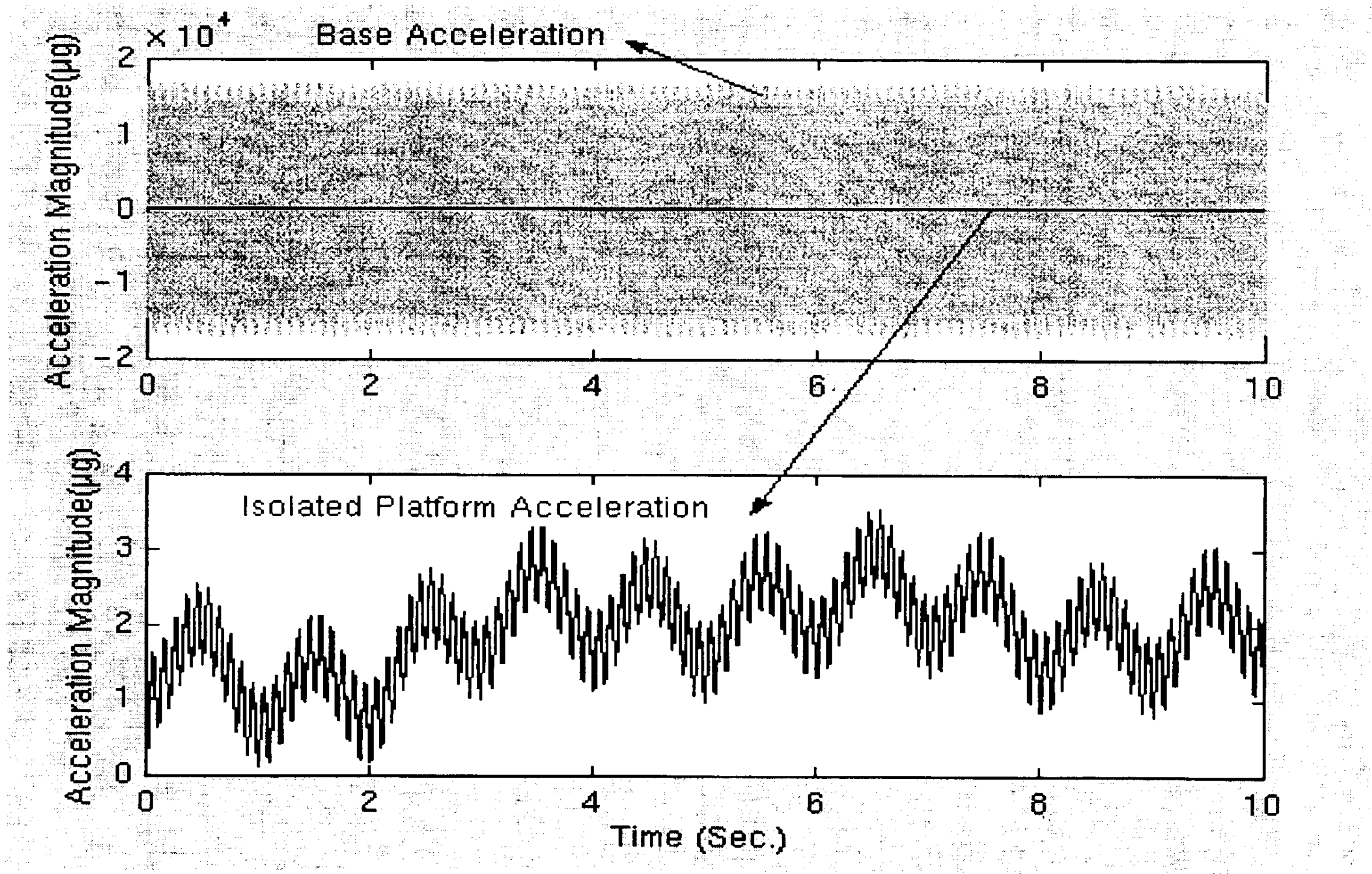


Brad Perkins, 6/29/00

National Aeronautics and Space Administration
Marshall Space Flight Center

Acceleration Time Response

Microgravity Science & Applications Department



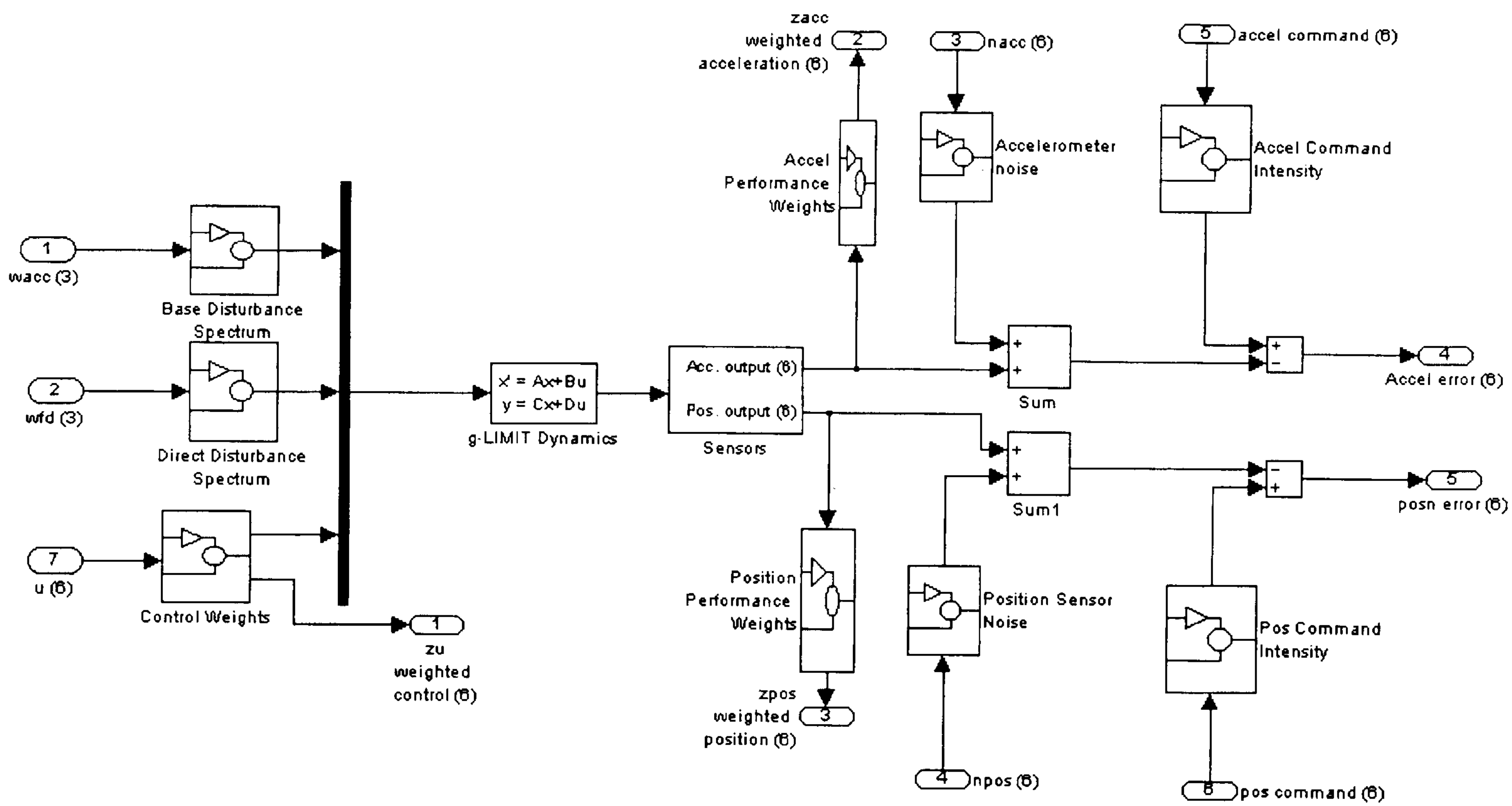
Base acceleration = 1.6 sin(0.01 hz*t)+16 sin(0.1 hz*t)+160 sin(1 hz*t)+1600 sin(10 hz*t)+16000 sin(100 hz*t)

Brad Perkins, 6/29/00

National Aeronautics and Space Administration
Marshall Space Flight Center

Generalized Plant for H2 Design

Microgravity Science & Applications Department



g-LIMIT
H_2 Control Design

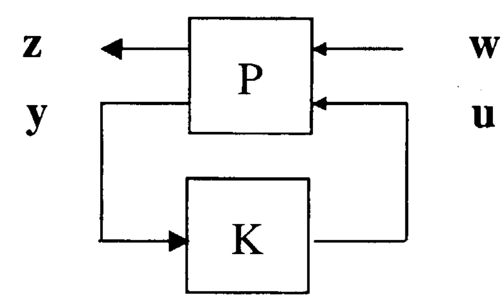
- H_2 Control Design Objective:
  - minimize H_2 norm of closed loop from disturbances, w, to performance variables, z

w =
- base acceleration
- payload induced force
- accelerometer noise
- position sensor noise

z =
- weighted control
- weighted acceleration
- weighted relative position

y =
- platform acceleration
- relative position

u = control actuators

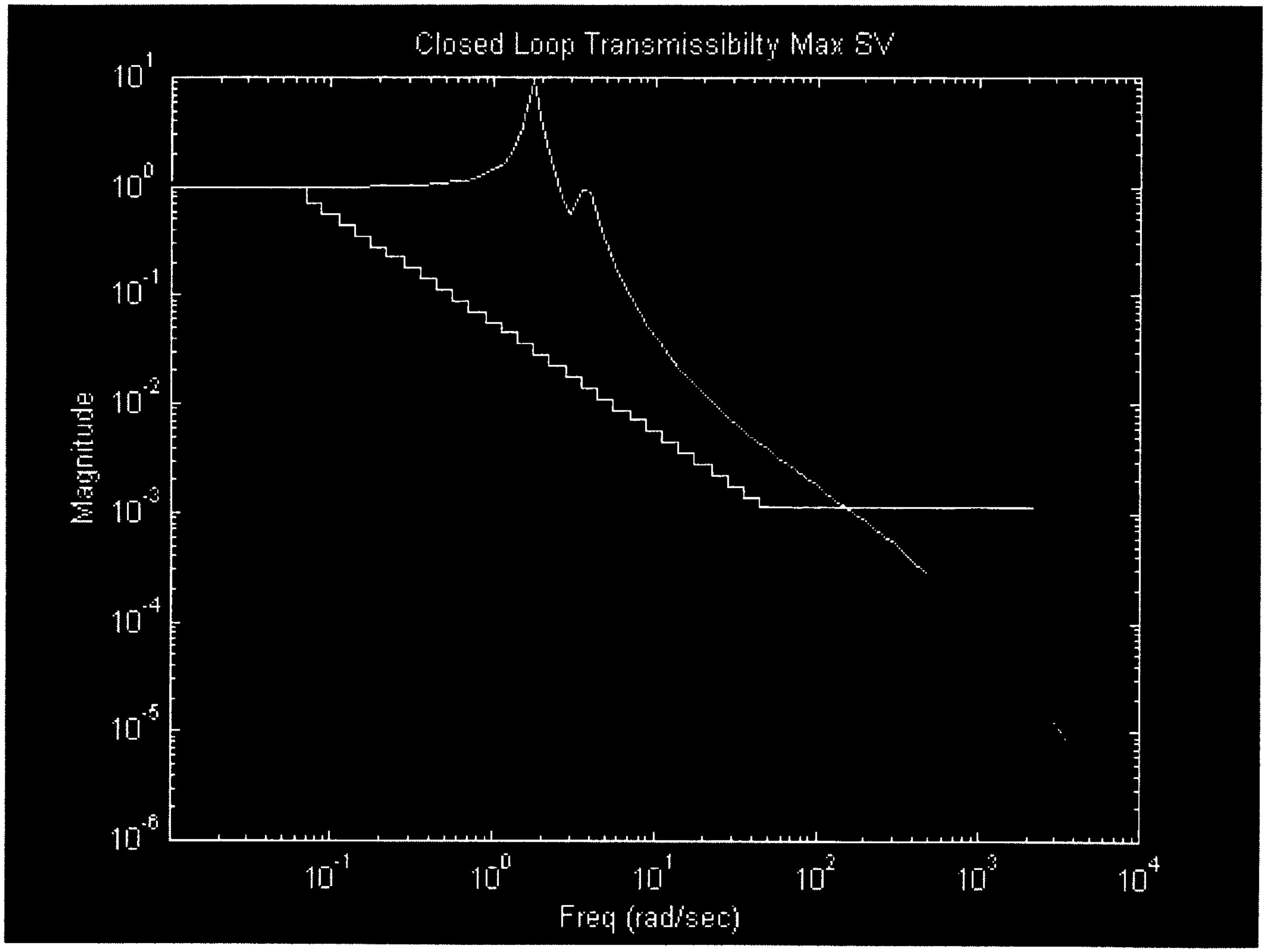


Brad Perkins, 6/29/00

National Aeronautics and Space Administration
Marshall Space Flight Center

H2 design

Microgravity Science & Applications Department



Brad Perkins, 6/29/00

Future Work

- Implement uncertainty model for H_∞ design - *in progress*
- Design Mixed H_2 /H_∞ controllers
- Optimize integrated performance of SISO position and acceleration loops
- Incorporate sampling and filter effects in analysis
- Implement digital form of the control algorithms
- Include parameter variations and nonlinear effects

5/5/37 9735 512580 2483

MGMG #19

Paper Number: 18

Fundamentals of microgravity vibration isolation

Mark S. Whorton
NASA Marshall Space Flight Center
Huntsville, Alabama

In view of the utility of space vehicles as orbiting science laboratories, the need for vibration isolation systems for acceleration sensitive experiments has gained increasing visibility. This presentation provides a tutorial discussion of microgravity vibration isolation technology with the objective of elaborating on the relative merits of passive and active isolation approaches. The concepts of control bandwidth, isolation performance, and robustness will be addressed with illustrative examples. Concluding the presentation will be a suggested roadmap for future technology development activities to enhance the acceleration environment for microgravity science experiments.

Fundamentals of Microgravity Vibration Isolation

Dr. Mark Whorton
g-LIMIT Principal Investigator
NASA Marshall Space Flight Center

Presented to the 19th Microgravity Measurements Group
Cleveland, Ohio
July 11-13, 2000

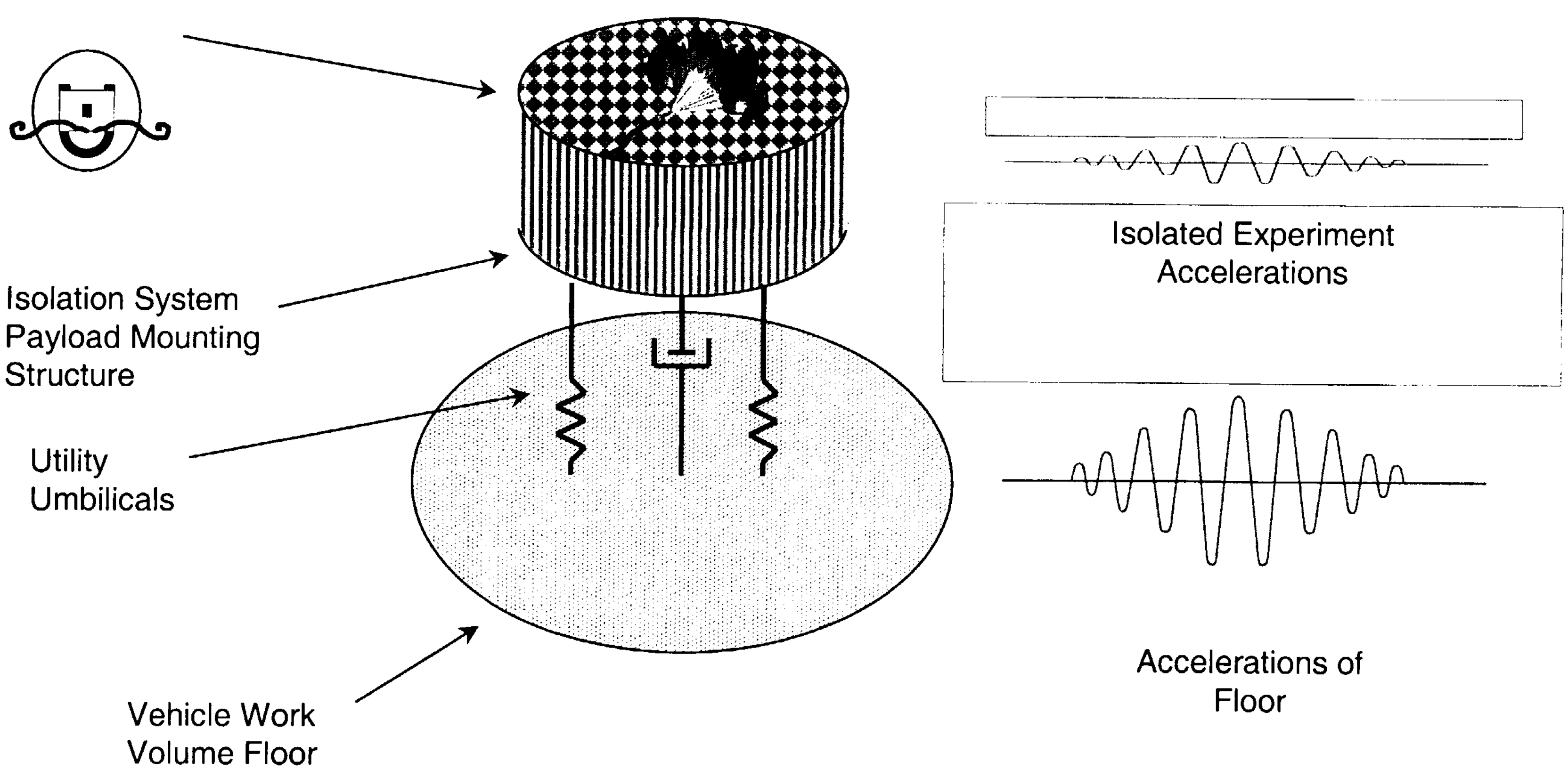
Outline

- Motivation for Vibration Isolation
- Passive Isolation Concepts
- Active Isolation Concepts
- Control System Design for
  Performance and Stability

Introduction

- The ambient spacecraft acceleration levels are often higher than allowable from a science perspective.
- To reduce the acceleration levels to an acceptably quiescent level requires vibration isolation.
- Either passive or active isolation can be used depending on the needs or requirements of a specific application.

What is Vibration Isolation?

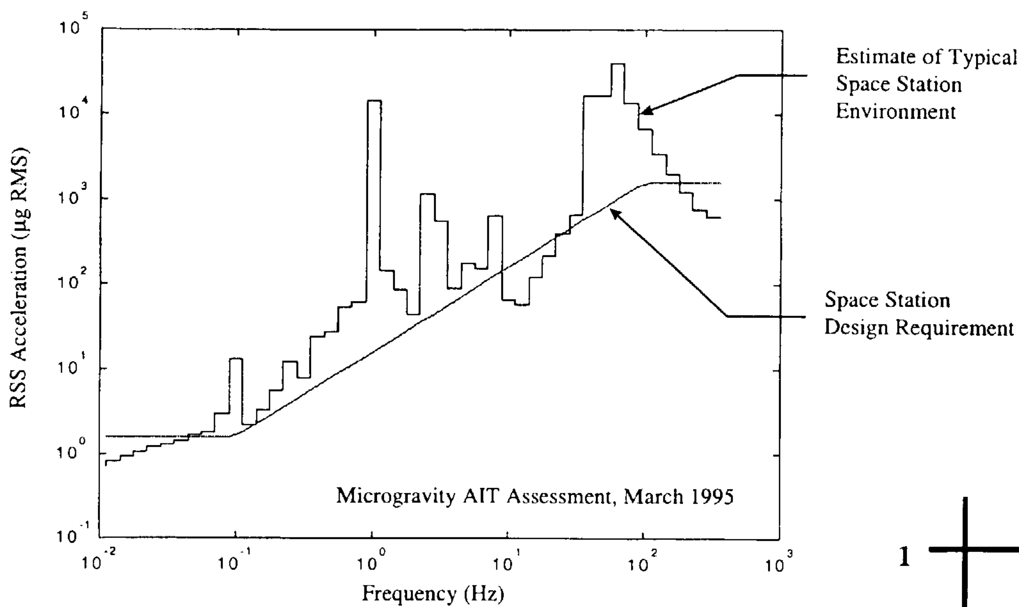


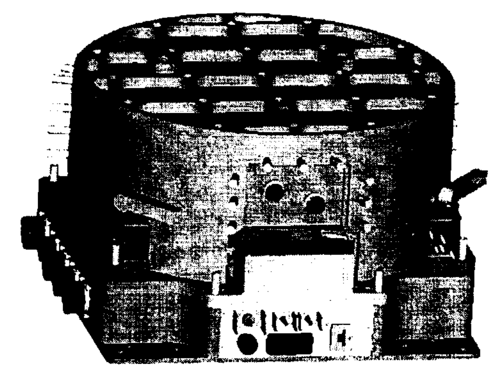
Mark S. Whorton
MGMG # 19, July 13, 2000

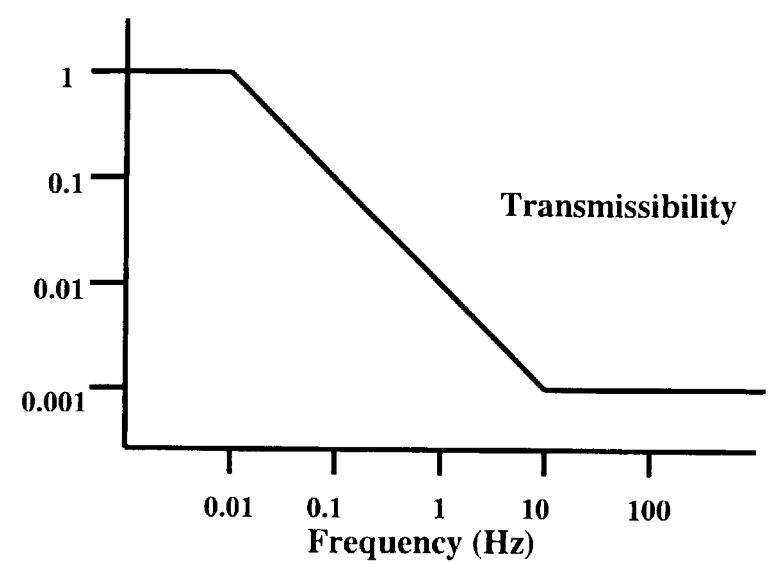
National Aeronautics and
Space Administration
Marshall Space Flight Center

Why is Vibration Isolation Needed?

MSFC Microgravity Science &
Applications Department





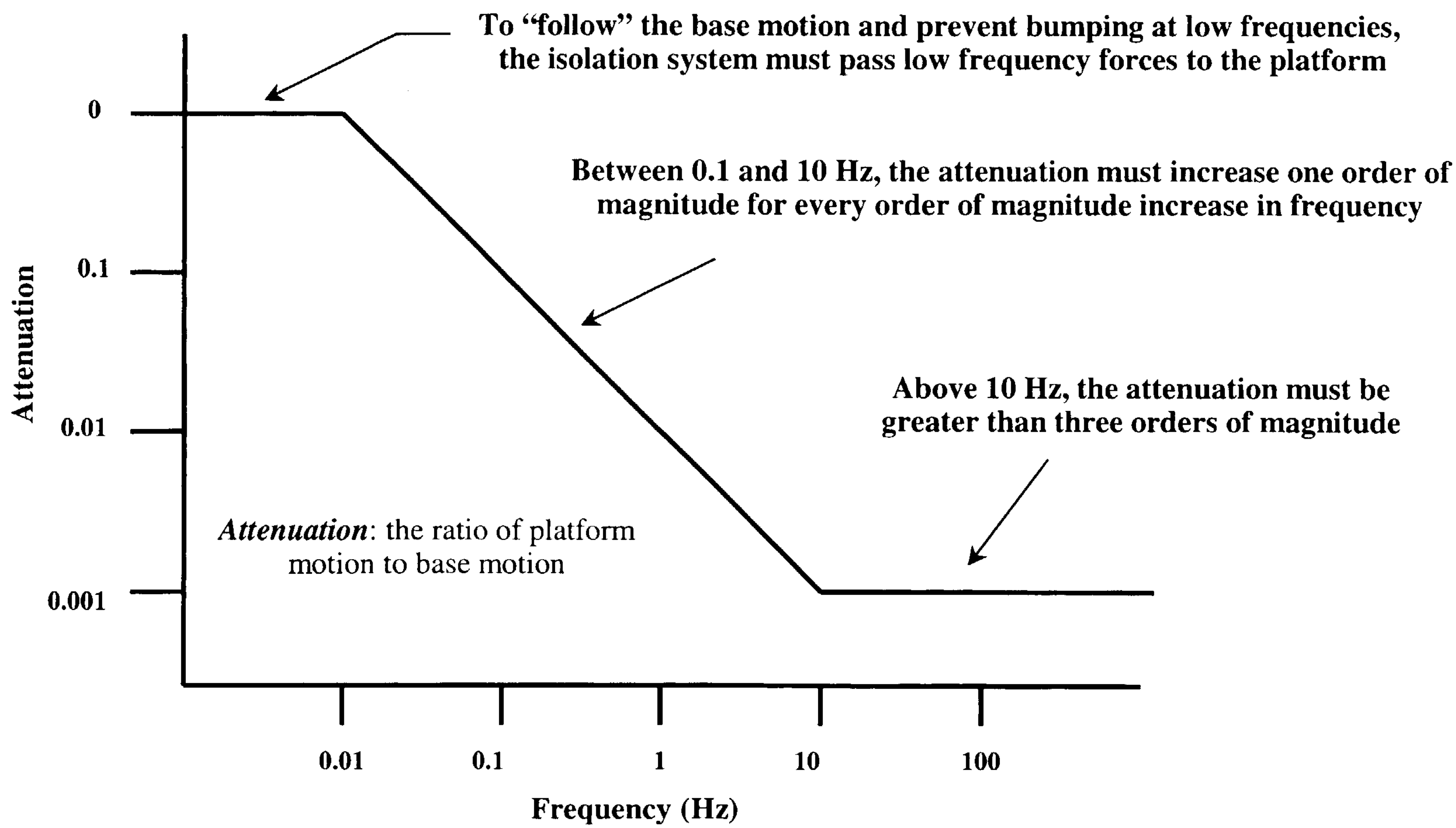


Mark S Whorton

National Aeronautics and
Space Administration
Marshall Space Flight Center

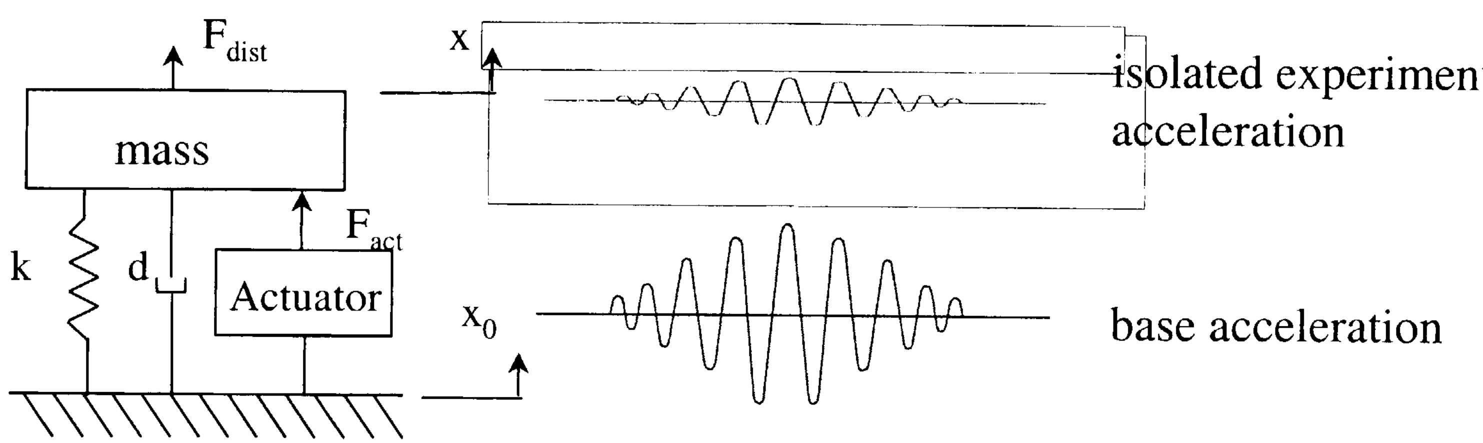
Attenuation Requirement

MSFC Microgravity Science &
Applications Department



Mark S. Whorton
MGMG # 19, July 13, 2000

Spring-Mass-Damper System



Equation of motion: $m\ddot{x} + d(\dot{x} - \dot{x}_0) + k(x - x_0) = F_{dist} + F_{act}$

Transmissibility:

•magnitude of transfer function from the acceleration (or position) response of the mass to the base acceleration (or position) input.

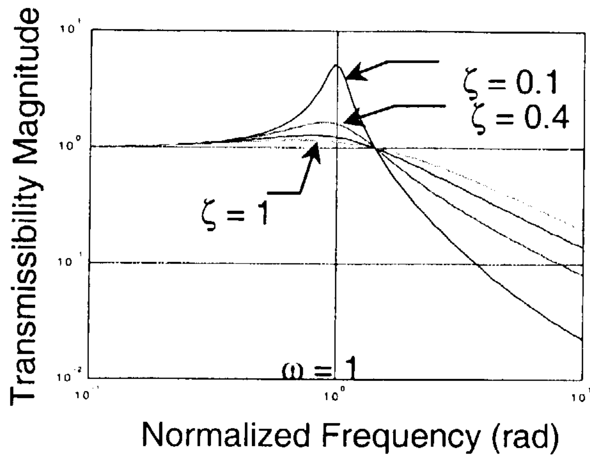
• specifies the attenuation of base motion as a function of frequency.

• use of springs, masses, and dampers for attenuation is known as ***"passive vibration isolation"***

Passive Isolation Approaches

Passive Vibration Isolation:

- Select spring stiffness, mass, and damping for attenuation
- Reduce break frequency by minimizing spring stiffness
  - Typically not desirable to increase isolated mass
- Select damping to trade between damped resonance and rate of attenuation



Transmissibility: $\dfrac{x}{x_0} = \dfrac{2\varsigma\omega s + \omega^2}{s^2 + 2\varsigma\omega s + \omega^2}$

Natural Frequency: $\omega = \sqrt{\dfrac{k}{m}}$

Damping Ratio: $\varsigma = \dfrac{d}{2\sqrt{km}}$

Active Control Approaches

Active Vibration Isolation:

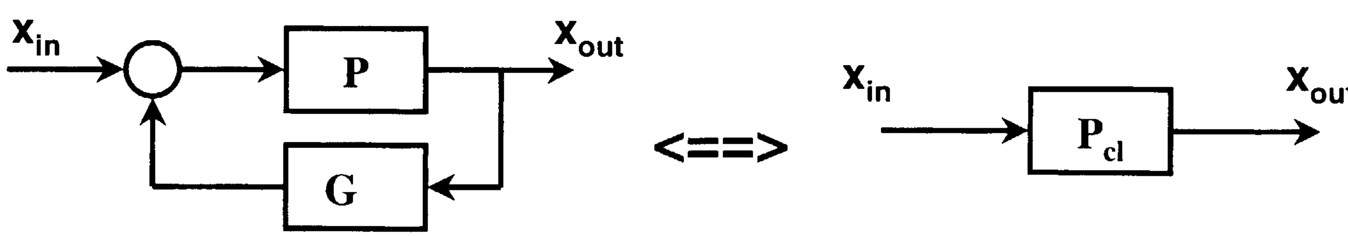
- Reduce the inertial motion of payload by sensing motion and applying forces to counter measured motion
- Active control can effectively change the system mass, stiffness, and damping ***as a function of frequency***
- Whereas passive isolation only attenuates forces in passive elements, active control attenuates measured motion
  - Only active control can mitigate payload response to payload-induced vibrations
- Requires power, sensors, actuators, control electronics (analog and digital)

Feedback Control Illustration

Consider the transfer function from base position to mass displacement:

$$P = \frac{ds + k}{ms^2 + ds + k}$$

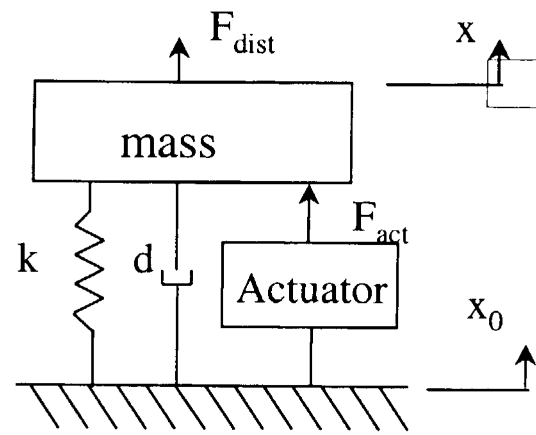
Now measure the displacement and "feed it back" with a control law given by $G = -K_a s^2 - K_v s - K_p$



The closed loop transfer function becomes:

$$P_{cl} = \frac{ds + k}{\underbrace{(m+K_a)}_{\tilde{m}}s^2 + \underbrace{(d+K_v)}_{\tilde{d}}s + \underbrace{(k+K_p)}_{\tilde{k}}}$$

Active Isolation Example



Recall the Spring-Mass-Damper Example

Equation of motion:

$$m\ddot{x} + d(\dot{x} - \dot{x}_0) + k(x - x_0) = F_{dist} + F_{act}$$

Consider the control law: $F_{act} = -K_a\ddot{x} + -K_v(\dot{x} - \dot{x}_0) - K_p(x - x_0)$

The resulting closed loop transmissibility is:

$$\frac{x}{x_0} = \frac{2\varsigma_{cl}\omega_{cl}s + \omega_{cl}^2}{s^2 + 2\varsigma_{cl}\omega_{cl}s + \omega_{cl}^2}$$

and the closed loop natural frequency and damping become:

$$\omega_{cl} = \sqrt{\frac{k + K_p}{m + K_a}} \qquad \varsigma_{cl} = \frac{(d + K_v)}{2\sqrt{(k + K_p)(m + K_a)}}$$

Passive & Active Isolation Comparison

	Passive Isolation	Active Isolation
Transmissibility:	$\frac{x}{x_0} = \frac{2\varsigma\omega s + \omega^2}{s^2 + 2\varsigma\omega s + \omega^2}$	$\frac{x}{x_0} = \frac{2\varsigma_{cl}\omega_{cl}s + \omega_{cl}^2}{s^2 + 2\varsigma_{cl}\omega_{cl}s + \omega_{cl}^2}$
Natural Frequency:	$\omega = \sqrt{\frac{k}{m}}$	$\omega_{cl} = \sqrt{\frac{k + K_p}{m + K_a}}$
Damping Ratio:	$\varsigma = \frac{d}{2\sqrt{km}}$	$\varsigma_{cl} = \frac{(d + K_v)}{2\sqrt{(k + K_p)(m + K_a)}}$

Comparison Summary

Type	Advantages	Disadvantages
Passive	•Low Cost •Low Maintenance •Reliable •No Power	•Isolate only higher freq (> 1-10 Hz) •Typically requires large volume •Cannot mitigate payload induced vibrations •Resonance vs attenuation trade
Active Rack Level (ARIS)	•Low freq attenuation •Min. power & volume (mult. payloads/single unit) •standard user interface	•Cannot mitigate payload induced vibrations •requires payloads to be "good neighbors" •highly sensitive to crew contact •potential maintenance & reliability issues
Active Sub-Rack Level (g-LIMIT, STABLE, MIM)	•Low freq attenuation •Mitigates payload induced vibration •can be optimized for individual user	•More power & volume than rack-level (single payload/single unit) •potential maintenance & reliability issues

Active Control Concepts

However, it isn't as easy as it seems –...

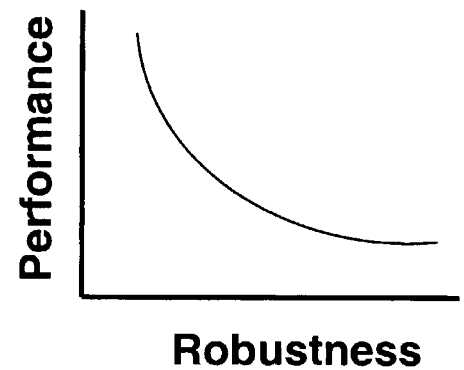
- Real systems are not lumped masses, springs, and dampers
- Real systems are coupled multiple degree of freedom systems
- Control system designs are based on properties that are typically not known well enough
- Control systems are limited by issues such as ***bandwidth*** and saturation

Key control design issues:

- ***Stability***: will the system return to an equilibrium position when disturbed?
- ***Performance***: how well is isolation achieved?
- ***Robustness***: how much uncertainty can be tolerated while preserving stability or performance?

Key Control Issues

Stability Robustness and **Performance** of a closed loop system are ***always*** in opposition



How much Robustness?

» uncertain umbilical properties
» uncertain structural modes
» mass and inertia variations
» multivariable coupling
» sensor & actuator dynamics

How much Performance?

» base motion attenuation
» payload disturbances
» forced excitation

Robustness vs. Performance

- Robustness to uncertainties:
  - umbilical properties
  - structural flexibility
  - mass and inertia variations
  - sensor & actuator dynamics

→ **Low Gain &/or Low Bandwidth**

- Performance:
  - base motion attenuation → **High Gain**
  - payload disturbances
  - forced excitation

→ **High Bandwidth**

Modern Control Approaches
to
Microgravity Vibration Isolation

Robust multivariable microgravity vibration control systems maximize performance for a specified bounded set uncertainties

Mark S. Whorton

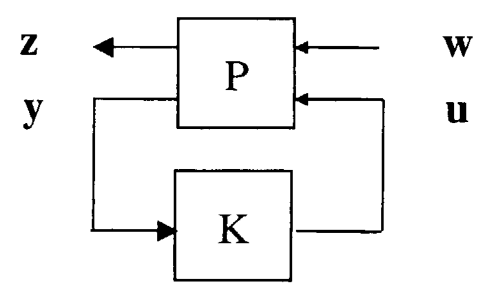
Design for Nominal Performance (NP)

H_2 Methods:

- Good nominal performance
- Performance metric well suited for μg vibration isolation
- Very poor robustness
- High order controllers

$$K_2 = \arg\left\{ \min_{K} \left\| T_{zw} \right\|_2 \right\}$$

where $\left\| T_{zw} \right\|_2 = \lim_{t \to \infty} E\{ z(t)^T z(t) \} \}$



$$K_2 : \left\{ \begin{array}{c} \dot{x}_c = A_c x_c + B_c y \\ u = C_c x_c \end{array} \right\} \qquad x_c \in \Re^{nc}$$

Design for Robust Stability (RS)

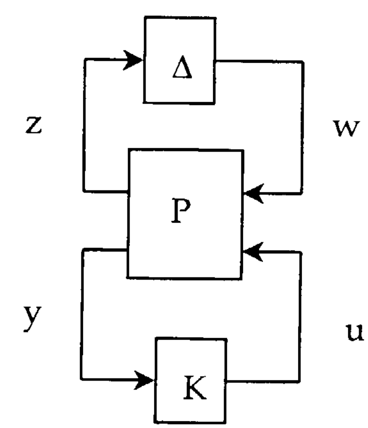
H_∞ Methods:

- Sufficient condition for RS of all plants in the set parameterized by the bounded model errors
  $\Delta \in \Delta_\delta, \Delta_\delta = \{\Delta : \|\Delta\|_\infty < \delta\}$ is $\|T_{zw}\|_\infty < \frac{1}{\delta}$
- Performance metric is the peak magnitude of transfer function – not well suited for μg vibration isolation
- High order controllers

$$K_\infty = \arg\left\{\min_K \|T_{zw}\|_\infty\right\}$$

where

$$\|T_{zw}\|_\infty = \sup_\omega \left\{\bar{\sigma}(T_{zw}(j\omega))\right\}$$



National Aeronautics and
Space Administration
Marshall Space Flight Center

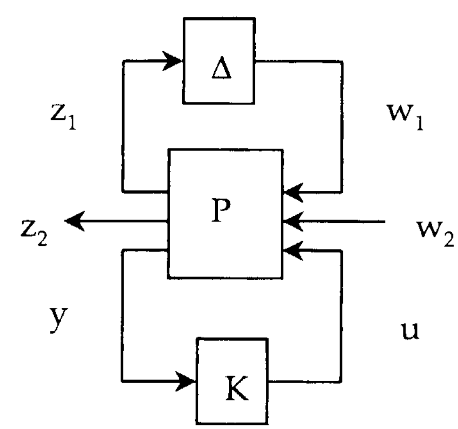
Design for Nominal Performance and Robust Stability

MSFC Microgravity Science & Applications Department

Mixed H_2 / H_∞ Methods:

- Optimizes H_2 nominal performance
- Guarantees H_∞ robust stability
- Optimized controller of FIXED DIMENSION
- Extremely computationally intensive
- Objective:
  - NP - $\min \|T_{z2w2}\|_2$

    Subject to
  - RS - $\|T_{z1w1}\|_\infty < \delta$

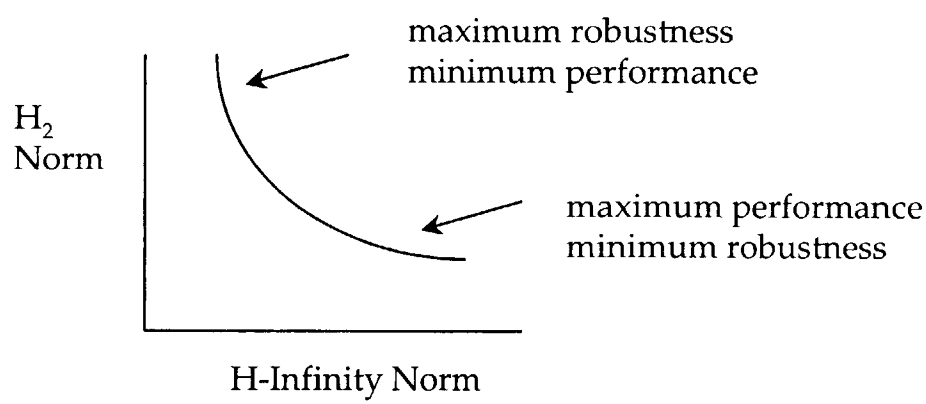


Mark S. Whorton

MGMG # 19, July 13, 2000

Fixed Order Mixed Norm Design Philosophy

- The utility of mixed norm design is exploited by separating performance and robustness using the most appropriate norms
- A set of controllers is designed that explicitly trades between RS and NP
- Determine maximum achievable performance subject to robust stability constraints



Future Directions for μg Vibration Isolation

- First generation isolation systems are currently in flight demonstration phase
- Once operational, will require significant sustaining engineering
  - payload scheduled control design
  - routine ongoing performance/stability analysis
  - loss of science time
- Second generation systems should provide better isolation performance in a more cost effective manner
  - maximize isolation performance
  - minimize payload impacts
  - autonomous operation & optimization

Adaptive Vibration Control Theory

Neural Network Based Adaptive Control Systems

- Accommodate payload uncertainties/variations
  - mass/inertia
  - structural modes
  - center of gravity
- Biologically inspired technology
  - autonomous adaptation
  - reduces sustaining engineering
  - maximize isolation performance
- Significant technology transfer potential
- Demonstrated in various aerospace vehicle applications

2001017738 512581 7/ps

Paper Number: 19

Active Rack Isolation System program and technical status

Glenn Bushnell
The Boeing Company
Seattle, Washington

Ian Fialho
The Boeing Company
Houston, Texas

The Boeing Active Rack Isolation System (ARIS) is one of the means used to isolate acceleration-sensitive scientific experiments from structurally transmitted disturbances aboard the International Space Station. The presentation provides an overview of ARIS and technical issues associated with the development of the active control system. An overview of ARIS analytical models is presented along with recent isolation performance predictions made using these models. Issues associated with commanding and capturing ARIS data are discussed and possible future options based on the ARIS ISS Characterization Experiment (ICE) Payload On-orbit Processor (POP) are outlined. An overview of the ARIS-ICE experiment scheduled to fly on ISS Flight 6A is presented. The presentation concludes with a discussion of recent developmental work that includes passive rack damping, umbilical redesigns and advanced multivariable control design methods.

References:

1. D.L. Edberg and B.W. Wilson, "Design and Testing of Reduced-Stiffness Umbilicals for Space Station Microgravity Isolation", AIAA Paper # 2000-1408 in Proceedings of the 41st AIAA Structures, Structural Dynamics and Materials Conference, Atlanta, April 2000.
2. I.J. Fialho and S.K. Thampi, "The Interplay Between Hardware and Control System Design in the Development of the Active Rack Isolation System", AIAA Paper # 2000-1818 in Proceedings of the 41st AIAA Structures, Structural Dynamics and Materials Conference, Atlanta, April 2000.
3. I.J. Fialho, "H• Control Design For The Active Rack Isolation System", Proceedings of the American Control Conference, pp. 2082-2086, Chicago, June 2000.

Active Rack Isolation System (ARIS) Program and Technical Status

Glenn Bushnell
Boeing, Seattle
glenn.s.bushnell@boeing.com

Ian Fialho
Boeing, Houston
ian.fialho@sw.boeing.com

James Allen
Boeing, Houston
james.allen@sw.boeing.com

Naveed Quraishi
NASA, JSC OZ3
naveed.quraishi1@jsc.nasa.gov

MGMG - Cleveland, July 13, 2000

Outline of Presentation

- **ARIS Modeling and Operation (Fialho)**
  - ARIS Control Models
  - Control Design Issues and Performance Limitations
  - ARIS Operation Overview
- **ARIS Baseline Performance (Bushnell)**
  - FCA-PCA Verification Results
- **Commanding and Capturing ARIS Data (Bushnell)**
  - Data Collection in RIC configuration
  - Data Collection in ICE-POP configuration
- **Levereging Off ARIS-ICE Hardware and Software (Bushnell)**
- **ARIS-ICE Overview (Fialho)**
  - Overview of ARIS-ICE tests
  - ARIS-ICE status
- **Ongoing Research and Development Directions (Fialho)**
  - Alternative controller design approaches (H_∞, μ)
  - Umbilical investigations
  - Passive Damping

ARIS MODELING AND OPERATION

The Active Rack Isolation System (ARIS)

ARIS Active Rack Isolation System

1 Dual Processor : Decoupling implemented in controller allows freedom to place actuators and sensors. Payloads have extensive command, data acquisition, and control options.

2 3 Sensor Electronic Units : Programmable analog filters & gains & 16 bit analog-to-digital converters.

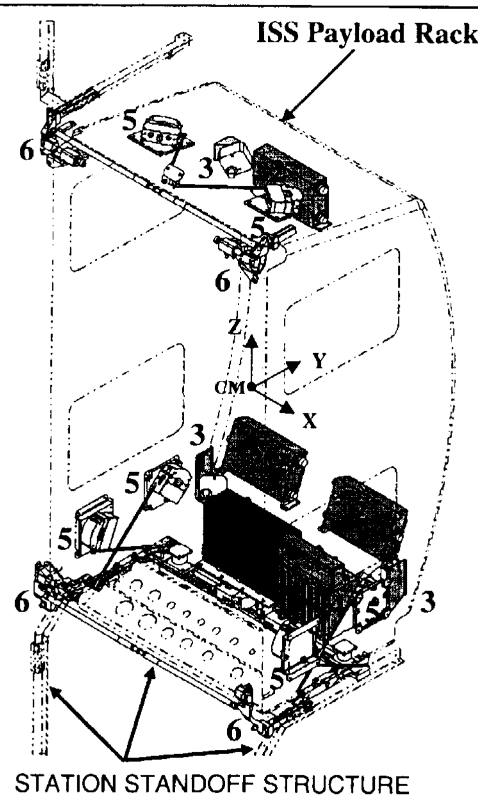
3 Accelerometer Heads : Built small to fit in rack corners. 3 Tri-axial heads.

4 8 Actuator Drivers : Pulse width modulation used to reduce power consumption

5 8 Actuators : Voice coil rotary actuator used to reduce profile and power consumption.

5 8 Position Sensors : Integrated with actuators.

6 Hard stop Bumpers

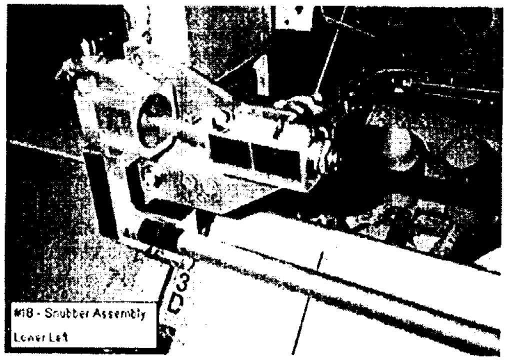


- **ARIS is a rack-level active vibration isolation system aboard the ISS**
- **ARIS components are integrated into ISS payload racks**
- **ARIS is part of an integrated station-wide isolation strategy**
- **ARIS umbilical system allows for Station resources, (power, low temp water, ethernet, 1553 cables etc.) to be passed to the rack**

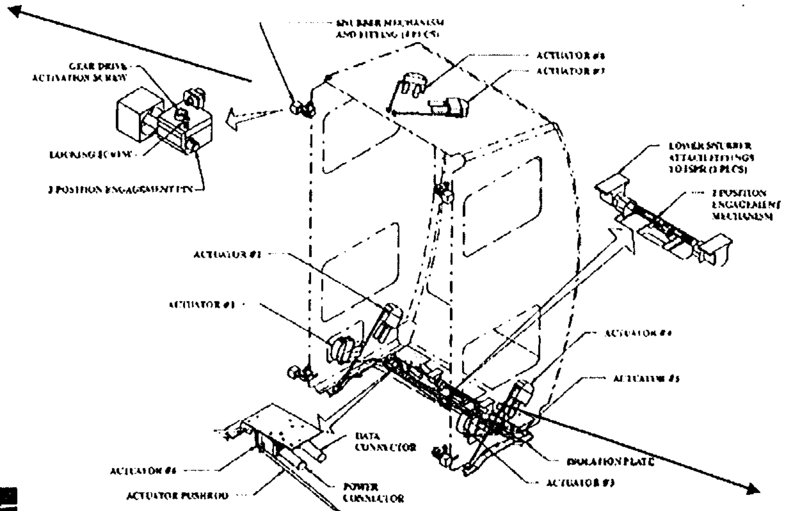
- ARIS Actuators
  - **Eight pushrods**, driven by rotary-type voice coil actuators (labeled 5)
- ARIS Sensors:
  - **Position sensors** housed in the actuator assembly are used to sense the relative position between the rack and the station
  - **Three triaxial accelerometer heads** (labeled 3) are used to sense rack acceleration

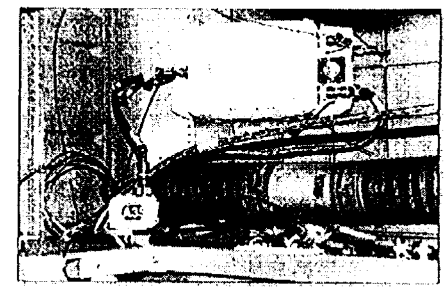
ARIS Components

ARIS Active Rack Isolation System



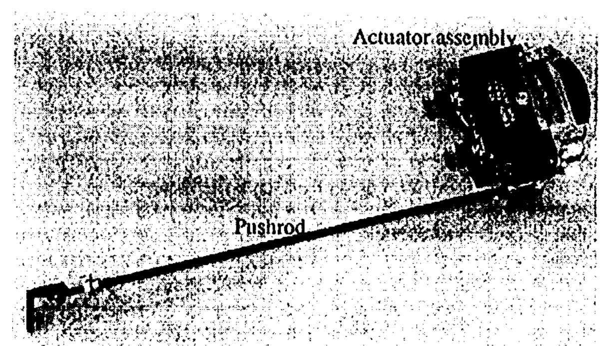
•Snubber cup and pin
•Limits rack motion to 0.5 inches

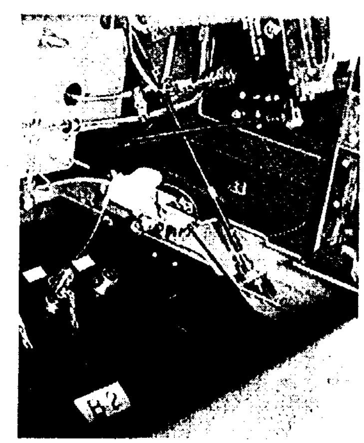




•Triaxial accelerometer heads and Remote Electronics Units

• ARIS umbilicals. Looped to reduce stiffness.
• Transfer data, power, water, nitrogen etc. to and from the rack





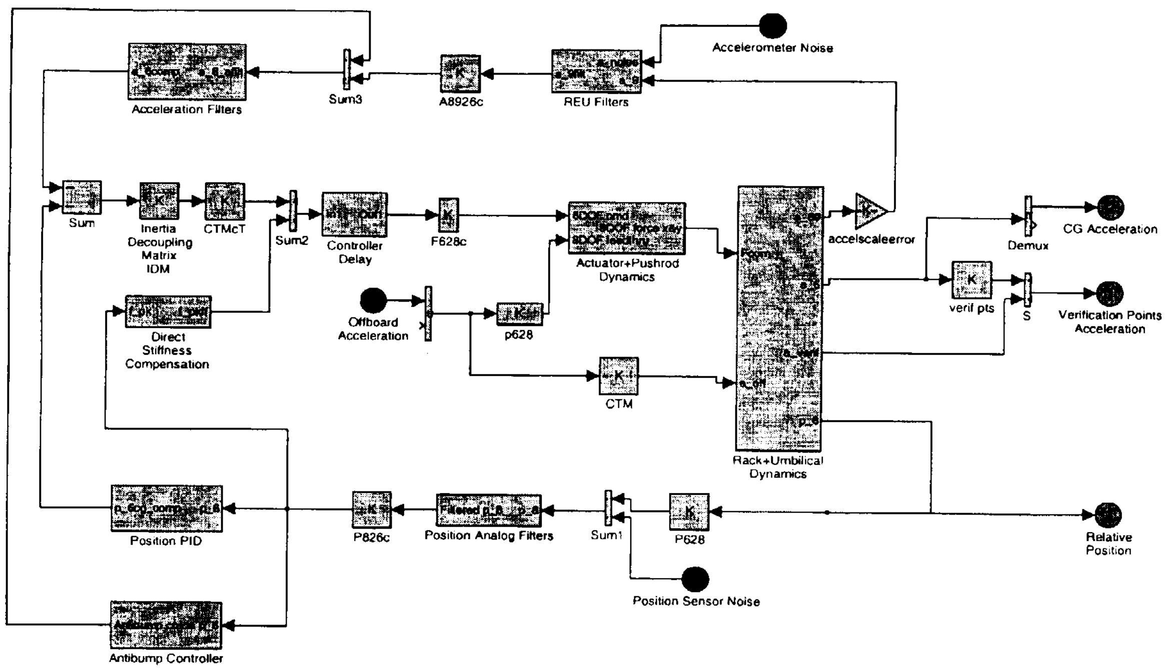
•ARIS actuator-pushrod assembly
•Position sensors housed in actuator assembly

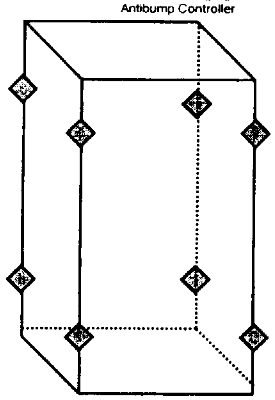
MGMG - Cleveland, July 13, 2000

5

ARIS Control Model

ARIS Active Rack Isolation System





- Onboard acceleration assessed at 8 verification points chosen to span a typical payload mounting volume
- <u>Control design objectives:</u>
  - **optimize isolation performance**
  - **provide low frequency position tracking**
  - **provide robustness to plant uncertainty**
  - **reject sensor noise**

Model Blocks:

Rack Dynamics:
- Mass-Spring Model of rigid rack and umbilical stiffness (includes umbilical hysteresis model)
- Model of rack flexible dynamics
- Model of umbilical dynamics

Actuator + Pushrod Dynamics:
- Second order model of voice coil assembly inertia and piano-wire compliance

Inertia Decoupling Matrix (IDM):
- Decouples dynamics into 6 independent DOFs

Direct Stiffness Compensation:
- Offdiagonal stiffness cancellation, and diagonal stiffness compensation

Position Analog Filters:
- Position loop filters

Position PID:
- Low frequency rack centering controller

REU Filters:
- Accelerometer filters

Acceleration Filters:
- Acceleration Loop Controller

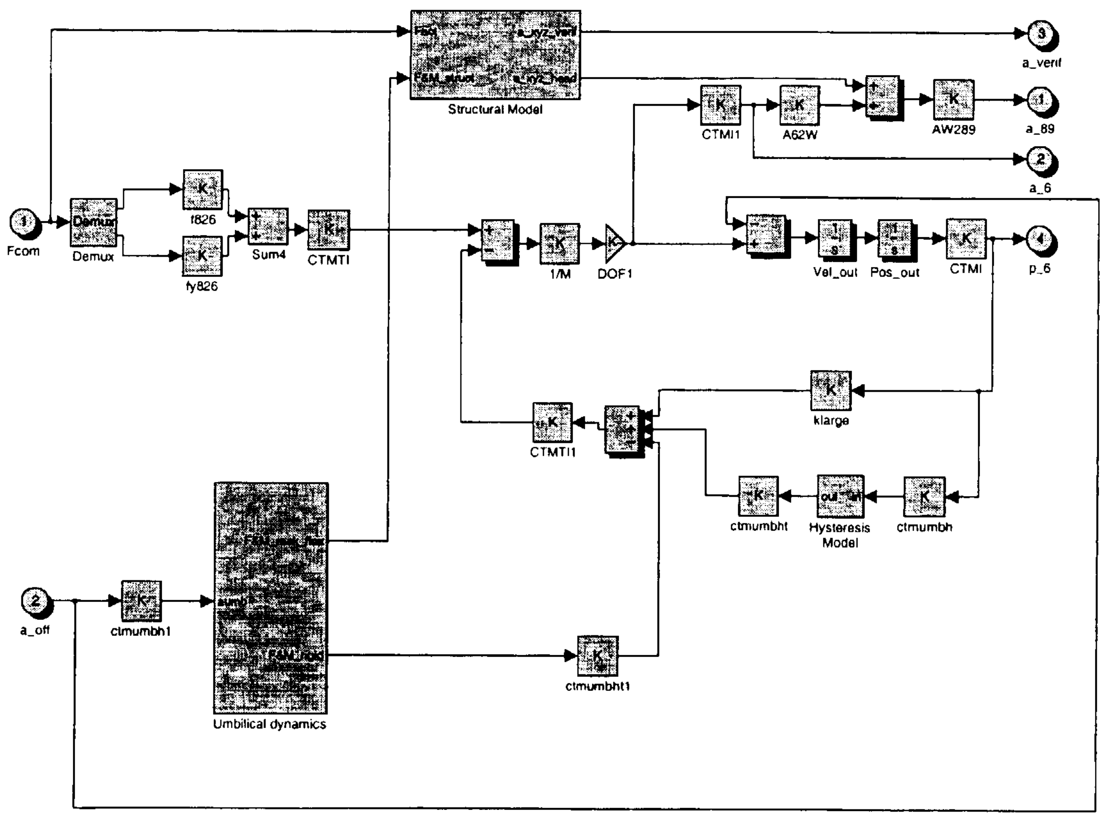
Antibump Controller:
- Outer loop controller that prevents bumping

MGMG - Cleveland, July 13, 2000

6

ARIS Control Model
(Rack + Umbilical Model)

ARIS Active Rack Isolation System



Model Blocks:

- **Mass-Spring model of rigid rack and umbilical stiffness:**

$$M\ddot{x} + K x = f$$

(K includes umbilical hysteresis model)

- **Structural Model :**
- FEM model of transfer functions from force at pushrod/umbilical attach points to acceleration at accelerometer heads and verification points.
- Structural model includes rack modes from 26 to 150 Hz.
- Natural frequencies and modal damping determined from modal tests.

- **Umbilical Dynamics:**
- FEM model of umbilical transfer functions from offboard acceleration to force at umbilical-rack attach points
- Partially test corellated

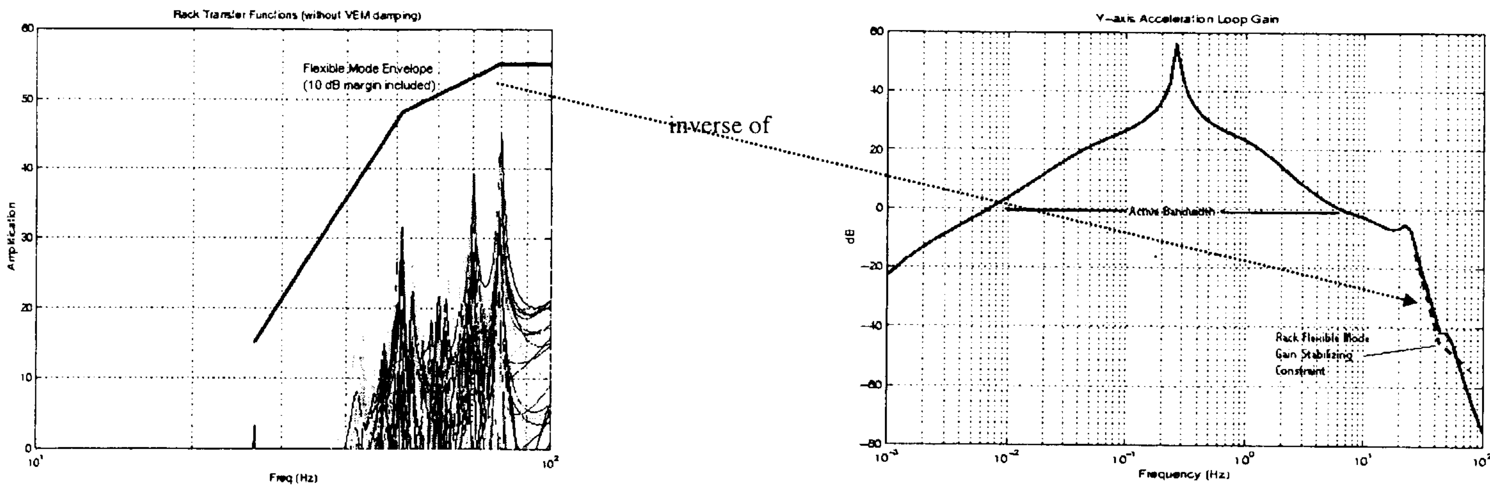
MGMG - Cleveland, July 13, 2000

Control Design Constraints (Plant Uncertainty)

ARIS Active Rack Isolation System

Rack Structural Dynamics

- Rack flexible modes exist above 26 Hz
- Significant uncertainty in damping, natural frequency and mode shapes (strongly configuration dependent)
- Acceleration loops must roll off to gain stabilize rack flexible modes
- Constrains acceleration bandwidth, and limits achievable isolation performance



Transfer functions from force at actuator attach points to acceleration at accelerometer locations

Typical open acceleration loop gain

•Constraint on acceleration loop bandwidth motivates the use of the position loop to perform stiffness compensation (limited by stiffness uncertainty and position sensor noise)

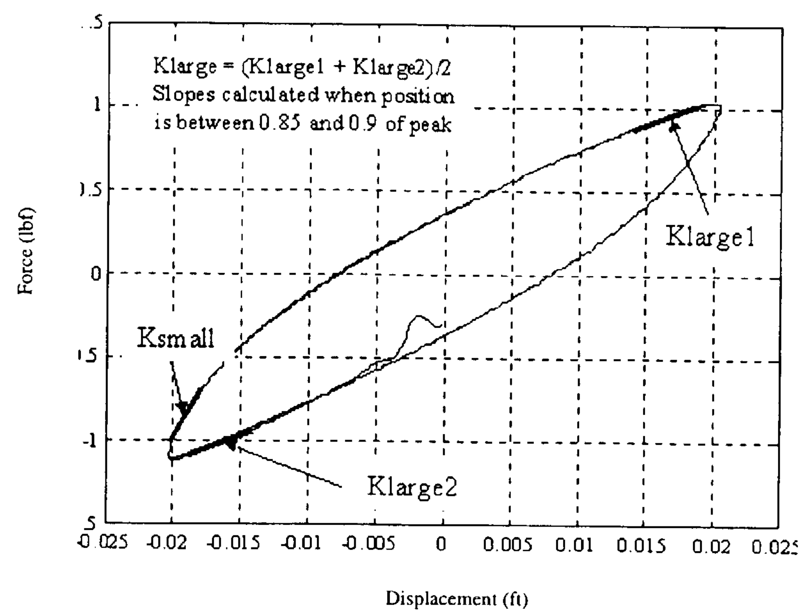
MGMG - Cleveland, July 13, 2000

Control Design Constraints (Plant Uncertainty)

ARIS Active Rack Isolation System

Umbilical Hysteresis

- Hysteretic force versus displacement curve
- Stiffness matrix K varies as a function of rack displacement ($K_{small} > K_{large}$)
- Places a restriction on the amount of direct stiffness compensation possible via the position loop
- Controller must provide:
  - robust isolation performance over K_{small} values
  - robust stability and low frequency robust isolation performance over K_{large} values



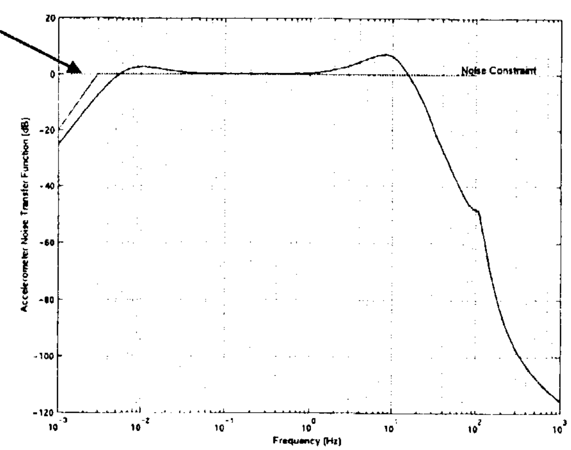
MGMG - Cleveland, July 13, 2000

Control Design Constraints (Sensor Noise)

ARIS Active Rack Isolation System

Accelerometer Noise

- Low frequency accelerometer noise causes rack motion (increases probability of bumping)
- Accelerometers are noisy at low frequency, requiring that restrictions be placed on the low frequency accelerometer loop gain
- Loop gain restriction imposed by constraint on transfer function from accelerometer noise to onboard acceleration



Position Sensor Noise

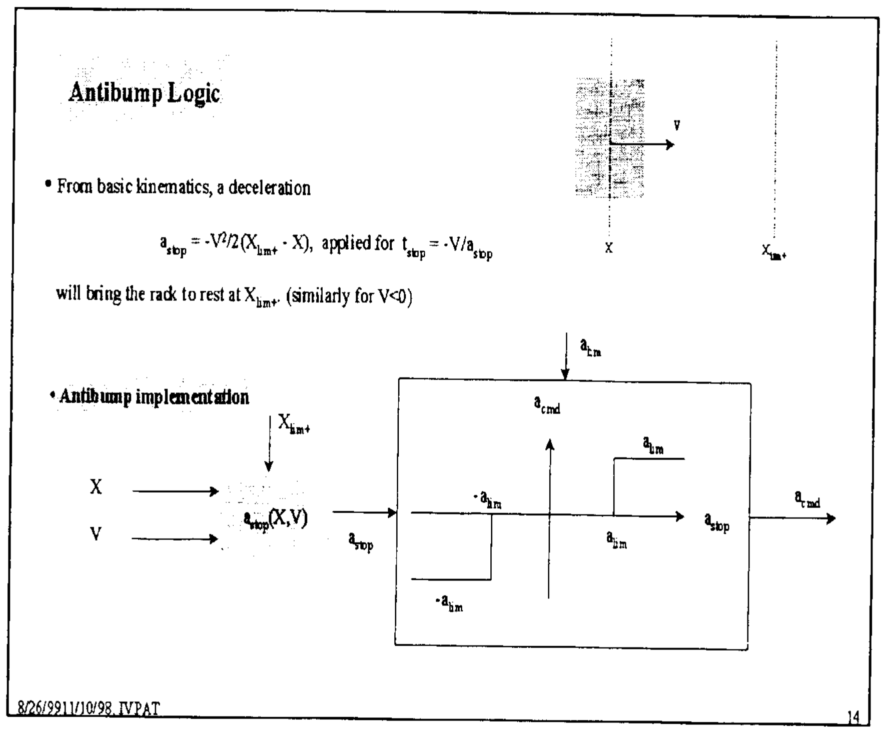
- Position sensors are noisy at high frequency
- Position loop must roll off to reject position sensor noise
- Places a restriction on the amount of direct stiffness compensation possible via the position loop

Control Design Constraints (Sway Space)

ARIS Active Rack Isolation System

Sway Space

- ARIS racks must operate within a $\pm$ 0.5 inch rattlespace
- Position PID authority is constrained by the low frequency isolation performance requirement
- Nonlinear outer loop antibump controller is used to ensure that bumping does not occur
- Increase in low frequency onboard acceleration levels when antibump is active
- X_{lim}/a_{lim} currently set at 0.25 inches/15 μg.



MGMG - Cleveland, July 13, 2000

ARIS Operation Overview
(User Selected Control Parameters and Filters)

ARIS Active Rack Isolation System

<u>User selected control parameters/filters are defined in three CNC files:</u>

- **Configuration file (.cfg) :** Direct stiffness compensation, IDM, REU filters, acceleration/position/force biases
- **Active parameters file (.act) :** Acceleration filters, position PID, antibump controller
- **Standby parameters file (.sby):** Position PID, antibump controller, acceleration filters (typically zero gain)

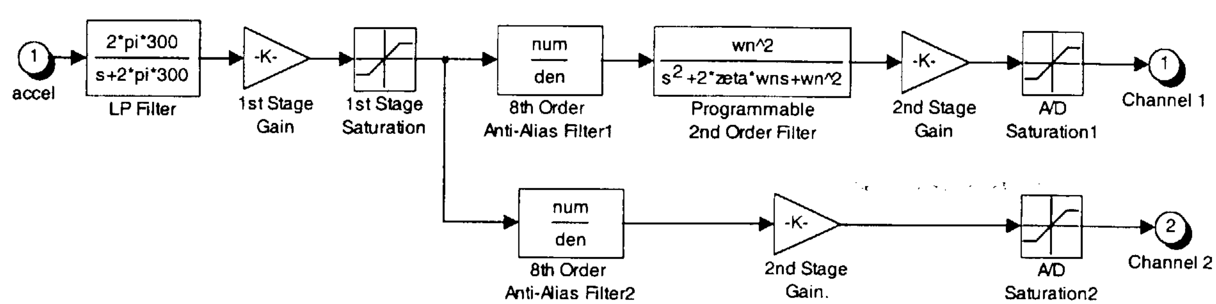
Appropriate files must be uploaded and reset in order to change parameters/filters.
Software is available to automatically generate .cfg/.act/.sby files.

•Acceleration Filters:

- Eight 2nd order filters in series per control channel (3 translation + 3 rotational)
- Numerator/denominator coefficients and gains specified by user

• REU Filters:

- User specified 2nd order filter and three gains per measurement channel (nine acceleration measurements)
- Gains and filter cutoff frequency/damping settings modify measurement resolution



MGMG - Cleveland, July 13, 2000

12

ARIS Operation Overview
(User Selected Control Parameters and Filters)

- **Inertia Decoupling Matrix (IDM):**
  - User specified 6x6 matrix = Rack Mass/Inertia Matrix
  - Rack mass matrix identified during ARIS setup

- **Direct Stiffness Compensation:**
  - 6x6 stiffness compensation matrix in series with one first order filter per control channel (3 translation + 3 rotation)
  - Matrix and filter numerator/denominator coefficients specified by the user
  - Umbilical stiffness matrix identified during ARIS setup

- **Position PID:**
  - PID gains (K_p, K_i and K_d) specified by user for each control channel (3 translation + 3 rotation)

- **Antibump Controller:**
  - X_{lim}/a_{lim} settings specified by user for each control channel (3 translation + 3 rotation)
  - Two 1st order and one 2nd order filter per control channel specified by user to shape antibump commands

ARIS-ICE OVERVIEW

ARIS-ICE Testing

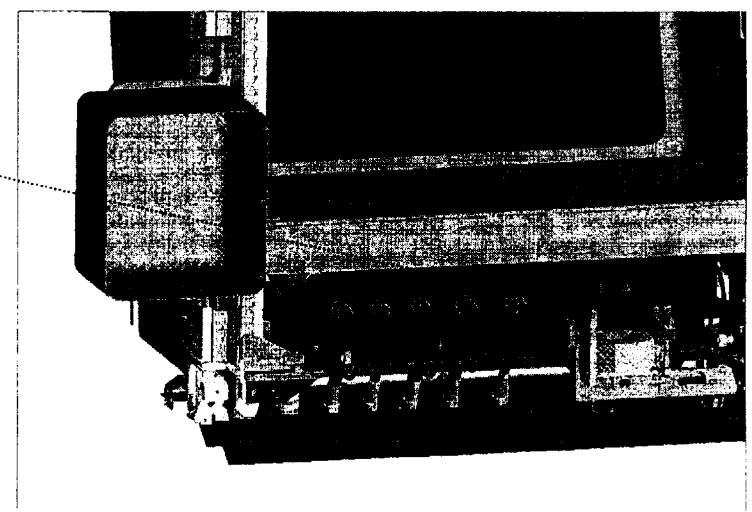
ARIS Active Rack Isolation System

ARIS-ICE Testing Objectives:
- Characterize on-orbit isolation performance (0.001 - 300 Hz) of a production ARIS unit, and use obtained data to correlate simulation models used for analytical predictions.
- Test design initiatives that have the potential to improve isolation performance:
    - Alternative umbilicals
    - Controller optimization
- Characterize effect of payload disturbances on onboard acceleration levels
- Gain on-orbit experience with nominal operation of ARIS.

Key ICE Hardware:

•Payload On-orbit Processor (POP)
- central command and data collection and processing computer
- interfaces with ARIS controller via dedicated 1553 and with SAMS-II hardware via Ethernet
- remotely commanded from the ground

•ICE Shaker
- PZT shaker provides high frequency (> 30 Hz) disturbance environment
- Shaker mounts on Z-panel and on rack seat-track
- manually operated by crew on orbit



•Alternate Umbilical Sets
- Looped and unlooped 888 and 448 EPTFE power cables
- Ground testing shows reduced resonance peaks compared to baseline ARIS cables

• ICE Hammer
- Impulse hammer for auxilliary tap testing

Support Hardware: SAMS-II and MAMS

MGMG - Cleveland, July 13, 2000

ARIS-ICE Testing

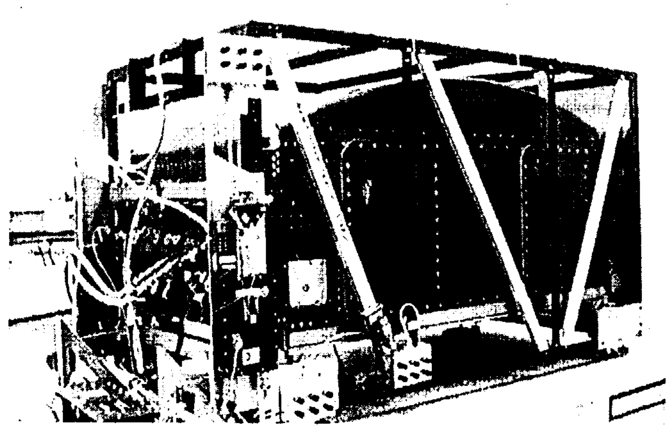
ARIS Active Rack Isolation System

ARIS-ICE Test Configurations

- Standard configuration (ARIS-RIC) and POP configuration (ARIS-POP)
- Full sway space and reduced sway space
- Baseline umbilicals and alternate umbilicals
- EXPRESS laptop connected and disconnected
- Shaker configuration (on-rack, off-rack)
- Orbiter docked and undocked
- Microgravity rack barrier connected and disconnected

ARIS 3DOF Testbed at SCTF, Houston

- ground testbed will serve mission training/planning for ICE and will serve as a testbed for future ARIS R&D activities



ARIS-ICE Tests

- Setup and Functional Tests:
    - Position loop stability tests
    - Sway space range test
    - Stiffness identification tests
    - Mass and Inertia identification tests
    - Compensation selection tests
    - Active control stability tests
- Quiescent Tests:
    - Crew asleep, PCS/AAA on/off
- Isolation Tests:
    - Crew awake, exercising
    - Shaker operational
    - Hammer Tap tests
    - Antibump active/inactive
- Controller Optimization Tests:
    - Position sensor bandwidth characterization
    - Stiffness compensation tests
    - High frequency compensation selection
    - Antibump modifications
- Crew Pushoff Tests
- Transition Transient Tests

ARIS-ICE Status

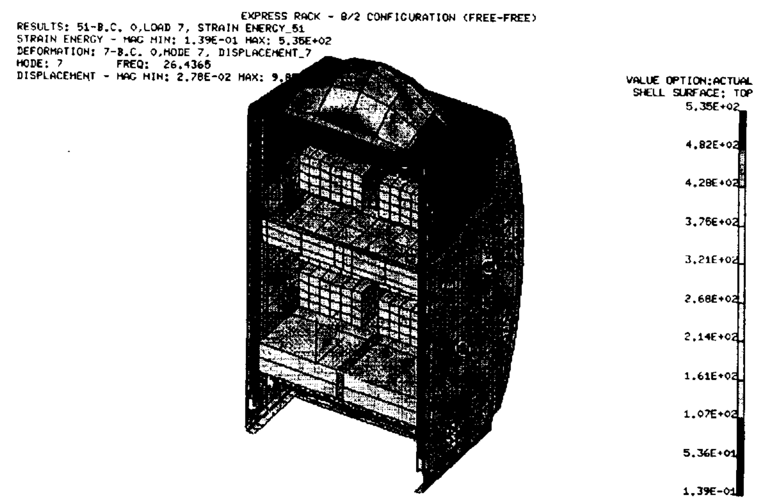
- ARIS-ICE DD250: 7/14/00
- KSC On-Dock: 7/24/00
- KSC Off-line testing: 7/26/00
- KSC Turnover: 7/31/00
- KSC On-line testing schedule under review by KSC
- 6A Launch: 4/19/01

ONGOING RESEARCH AND DEVELOPMENT DIRECTIONS

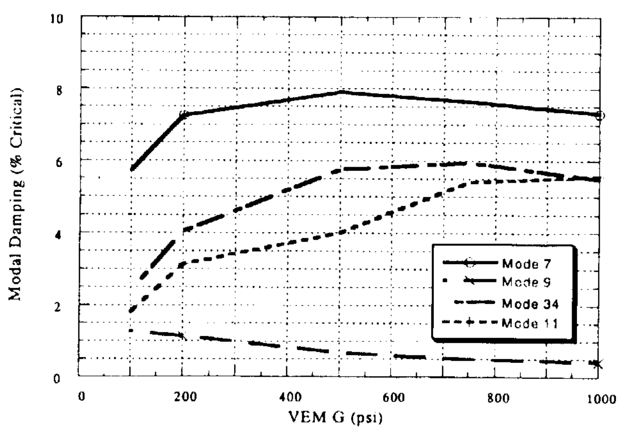
Rack Damping

- **Constrained Layer Damping Treatments (CLD)**
  - CLD treatments can be used to increase damping in targeted rack modes
  - Treatments incorporate highly dissipative visco-elastic materials (VEM)
  - Design of damping treatments based on Modal Strain Energy method

$$\eta^{(r)} = \sum_{i=1}^{M} \eta_i \frac{SE_i^{(r)}}{SE^{(r)}}$$



- **Analytical studies**
  - Analysis based on test-verified finite element models
  - Six modes below 50 Hz targeted for damping
  - Parametric studies performed for design optimization



- **Final Design**
  - 0.04" thick ISD 112 VEM, 0.08" thick Al constraining layer
  - Design goal of 5% modal damping met in most of the targeted modes

MGMG - Cleveland, July 13, 2000

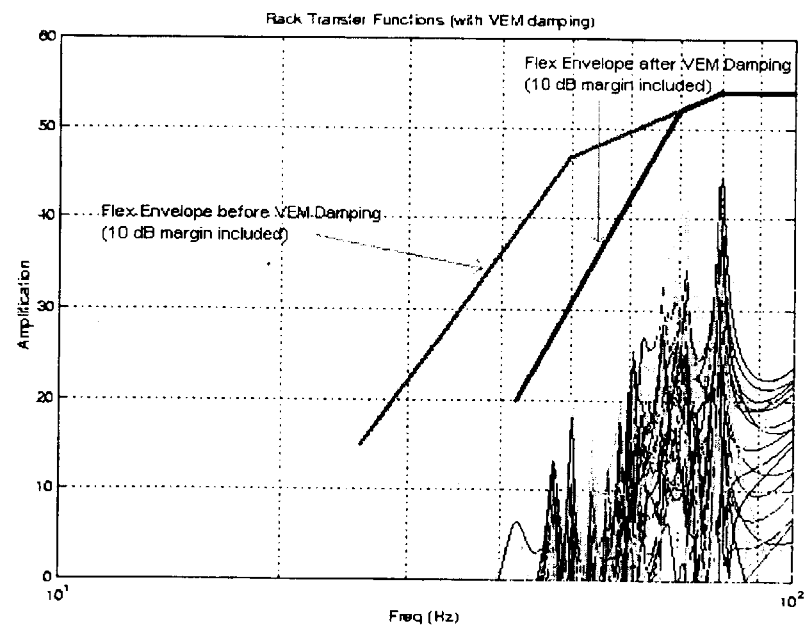
19

Rack Damping

- **CLD treatments that target only the lower frequency rack modes (26-52 Hz) were attempted:**
  - **The acceleration loop rolloff design is strongly driven by the segment of the gain stabilizing constraint that corresponds to the lower frequency (26-52 Hz) modes, and hence from the viewpoint of maximizing bandwidth these modes are most significant.**

Baseline Mode #	Baseline Frequency Hz.	Damping on all features Mode #	Damping on all features Frequency Hz.	Damping % Critical	Description
7	26.44	**7**	**28.06**	**7.24**	Top Panel, First Bending
8	38.22	8	38.22	0.01	Bottom Shelf
9	41.90	**9**	**42.16**	**1.23**	Rack Frame Torque
10	43.13	**17**	**57.50**	**10.30**	Hardback, First Bending
11	45.11	**10**	**45.62**	**3.11**	Top Panel, 2nd Bending
12	47.24	11	47.22	0.01	Rack Pinching
13	47.57	12	47.58	0.02	Top Panel ?
14	50.01	13	50.03	0.00	Left Side Panel (Middle)
15	50.12	**27**	**63.49**	**2.89**	Right Side Panel (Rear Mt. Plt)
16	50.35	14	50.35	0.00	Right Side Panel (Middle)
17	51.11	**29**	**65.29**	**5.59**	Left Side Panel (Rear Mt Plt)
18	53.45	15	53.39	0.02	
19	56.27	16	56.27	0.03	
20	58.38	18	58.38	0.03	

Modal damping achieved



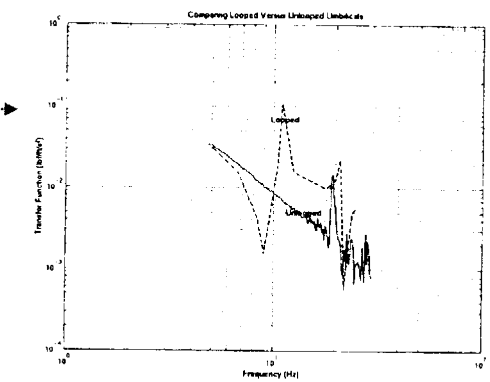
Effect of CLD treatment on rack flexible mode envelope

MGMG - Cleveland, July 13, 2000

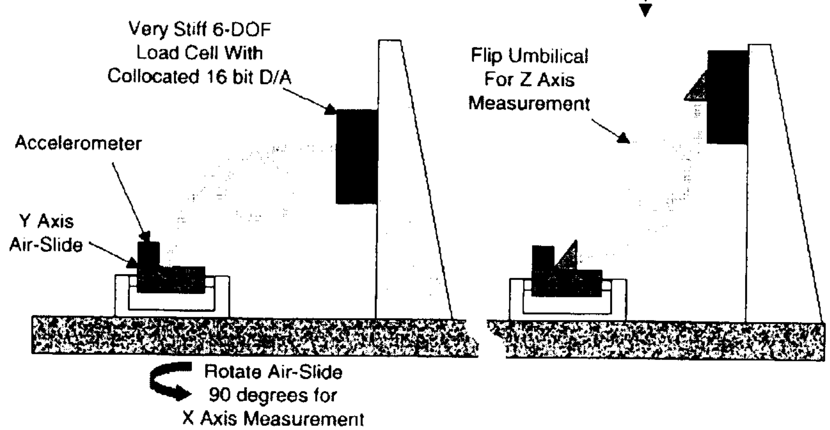
20

Alternate Umbilical Designs

- Unlooped Umbilicals
  - Resonance at 10 Hz is due to loop resonance of the baseline 6 kW power umbilicals
  - Removing umbilical loop eliminates 10 Hz resonance
  - Various wire gauge/strand/insulation combinations have been investigated to make umbilicals as close to a "pure spring" as possible
  - Unlooped 888 and 448 EPTFE umbilicals will be tested on ICE



- Umbilical Research
  - Analytical computation of umbilical stiffness and resonances
  - Understanding the physical mechanism that causes hysteresis
  - Development of umbilical test facility
  - FEM modeling of umbilicals and corellation with test data

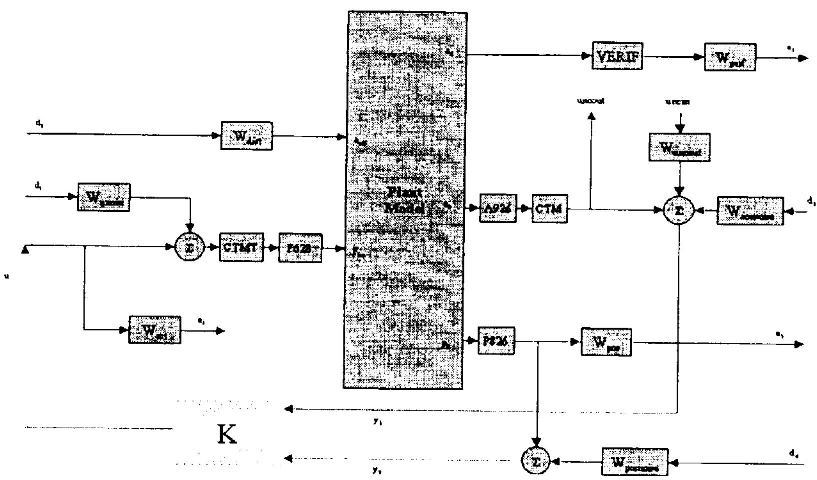


MGMG - Cleveland, July 13, 2000

21

Alternate Control Design Approaches

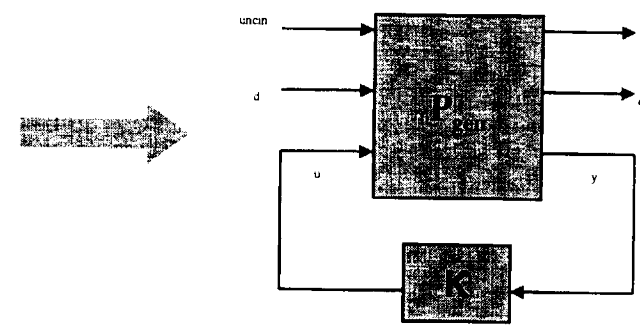
- **Controller design using H_∞ methods:**



H_∞ control design interconnection

Design Weighting Functions:

- W_{dist}, W_{perf} : isolation performance
- W_{pos} : low frequency position tracking
- $W_{posnoise}$: limits position loop bandwidth
- W_{uncout} : acceleration loop rolloff
- $W_{accnoise}$: low frequency accelerometer noise rejection
- W_{uncin} : robustness to stiffness variations
- W_{act} : limit actuator force



Lower LFT form

Design K to minimize H_∞-norm from inputs to outputs

- **optimize performance subject to robustness and noise constraints**
- **optimize the acceleration/position loop tradeoff**
- **significant reduction in the control design cycle time; important for on-orbit controller optimization**
- **will require modification of the ARIS control law implementation architecture**
- **other approaches μ, H_2, mixed-norm will also be studied**

MGMG - Cleveland, July 13, 2000

22

PHANTOM WORKS

ARIS Configuration & Coordinate Frame

ARIS Active Rack Isolation System

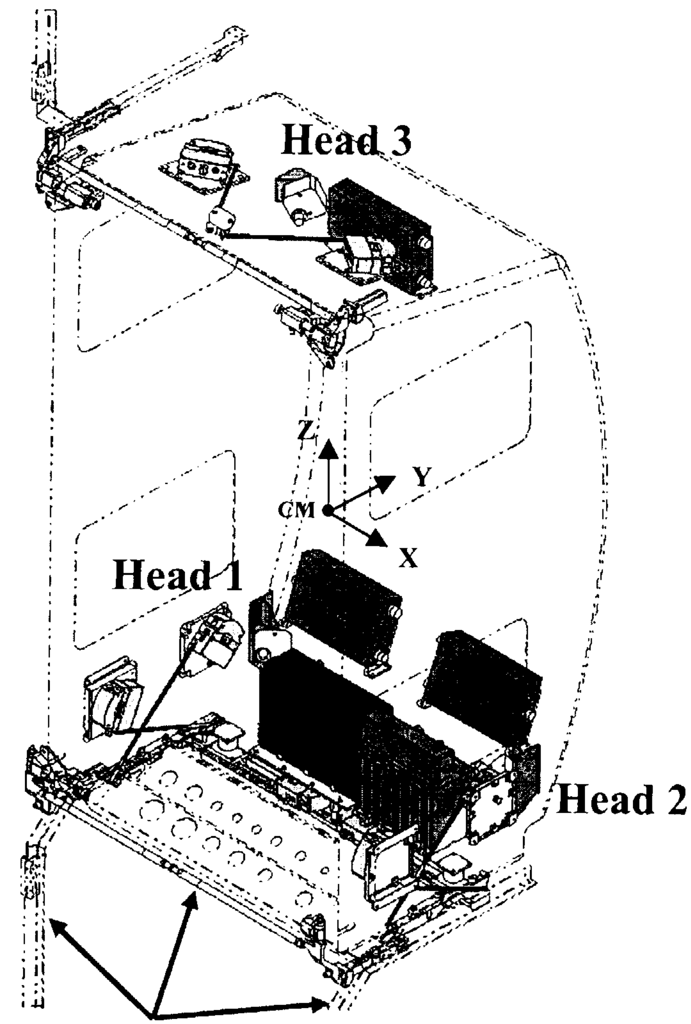
Rack Attach Point Inputs

- 8 Actuators
- 14 Umbilicals

Rack Attach Point Outputs

- 3 Accelerometer Heads
- 8 Verification Points On Rack Posts

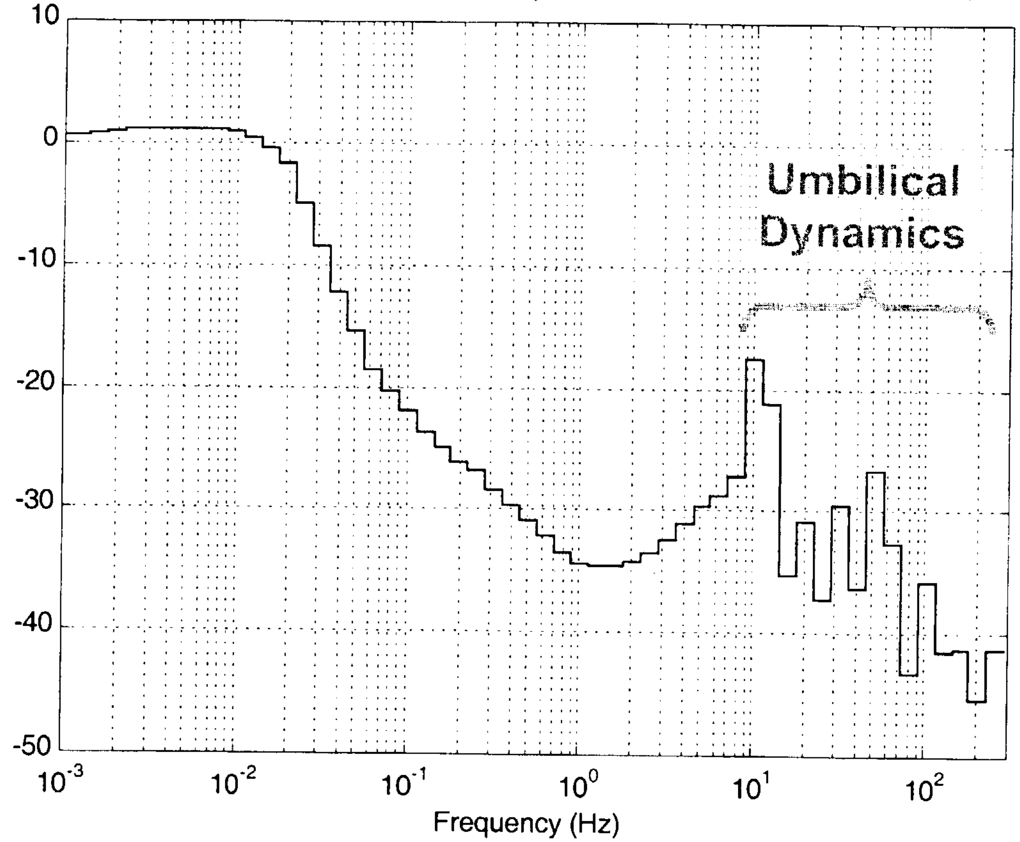
Verification Point Model Coordinates (inches)			
Location	X	Y	Z
H1	-22.48	-11.26	22.78
H2	18.6	-11.26	22.78
H3	18.6	14.24	22.78
H4	-22.48	14.24	22.78
K1	-22.48	-11.26	-22.72
K2	18.6	-11.26	-22.72
K3	18.6	14.24	-22.72
K4	-22.48	14.24	-22.72



1

ARIS Predicted Isolation Performance
Rigid Rack, 1272 lbs

Worst case isolation, CG Variations, Worst VP, Worst Input Direction, Worst Ksmall corner 3 or 5, Rigid Rack



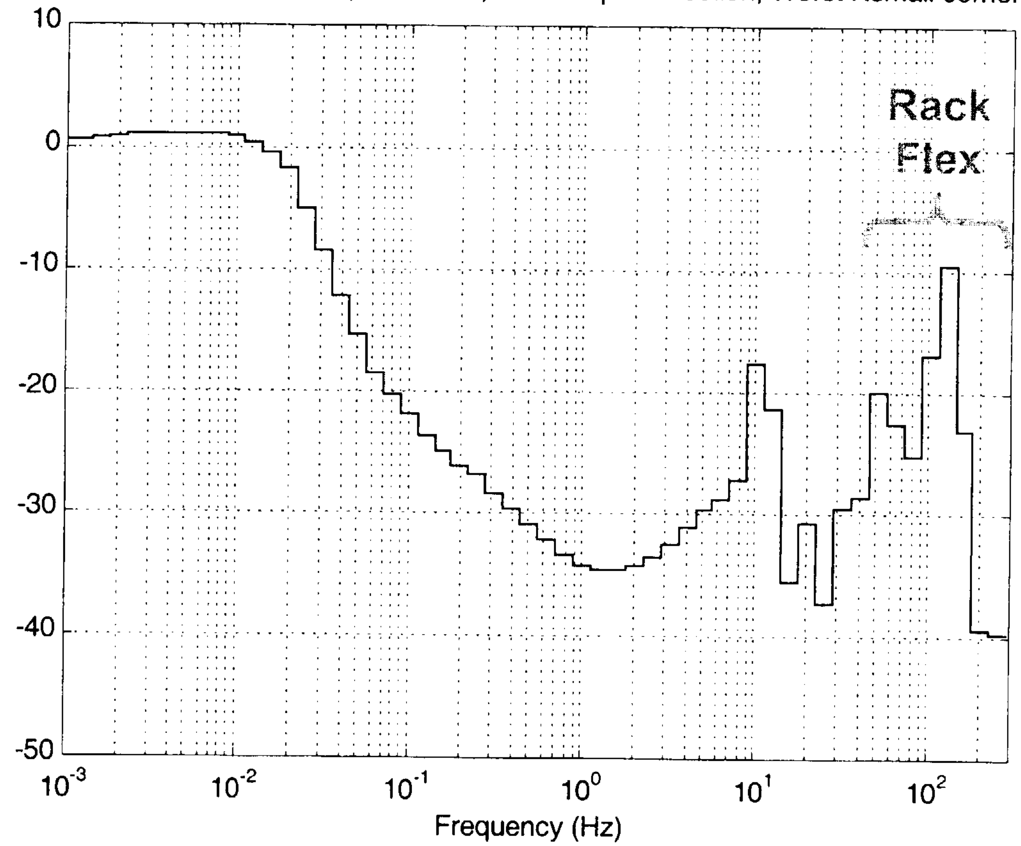
- Predict 12 dB better isolation at 10 Hz with redesigned 6 KW power umbilicals

BOEING
PHANTOM WORKS

ARIS Predicted Isolation Performance
Flexible Rack

ARIS Active Rack Isolation System

Worst case & Nominal isolation, CG Variations, Worst VP, Worst Input Direction, Worst Ksmall corner 3 or 5, Rigid Rack



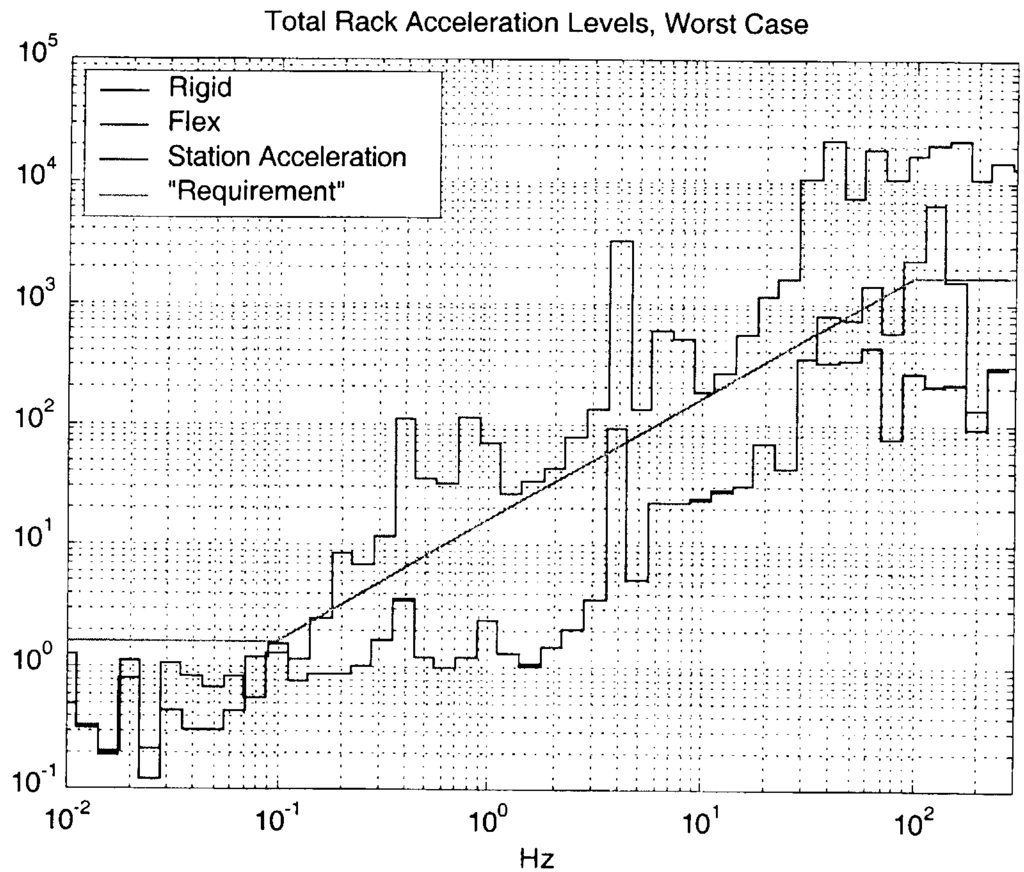
- NASTRAN model of EXPRESS rack includes modes out to 150 Hz

3

BOEING
PHANTOM WORKS

Predicted Station Acceleration (DAC8) and Rack Acceleration Levels, Anti-Bump On

ARIS Active Rack Isolation System



- Rack levels include combined response to, 1) 8 non-vent station transient disturbances, 2) the worst case station vent disturbance, 3) station steady state disturbances, 4) ARIS acceleration measurement noise, and 5) ARIS equipment.

4

DAC8 Maximum Bumper Displacements

DAC8 40 psia / 250 L	d. (in)
ESA_Vent	0.47
Lab_Vent	0.12
JEM_Vent	0.44

DAC8 14.7 psia C/ 100 L	d. (in)
ESA_Vent	0.06
Lab_Vent	0.02
JEM_Vent	0.06

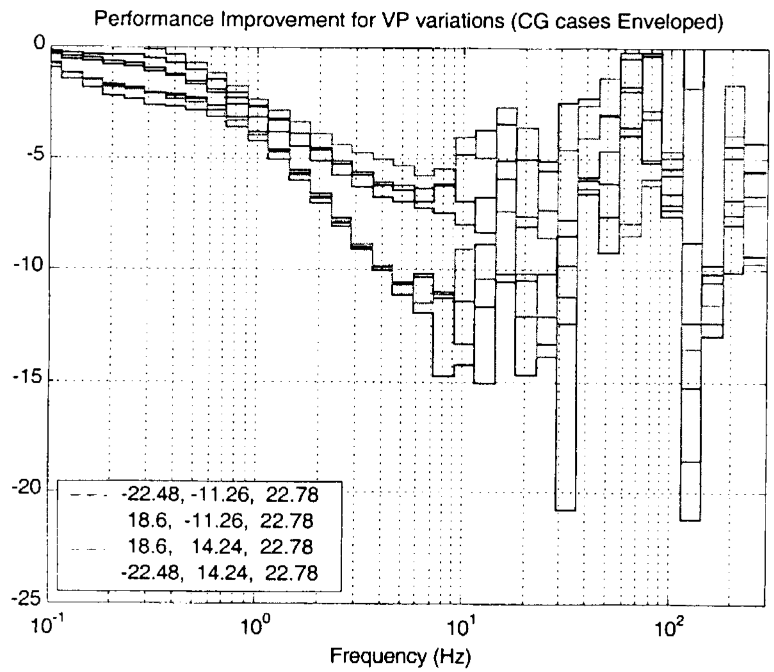
40 psia / 250 L	Response In COF
ESA2 Vent + Non-vent transients + acceleration noise	0.62 inches
ESA2 Vent + Non-vent transients + acceleration noise + antibump	0.27 inches

BOEING
PHANTOM WORKS

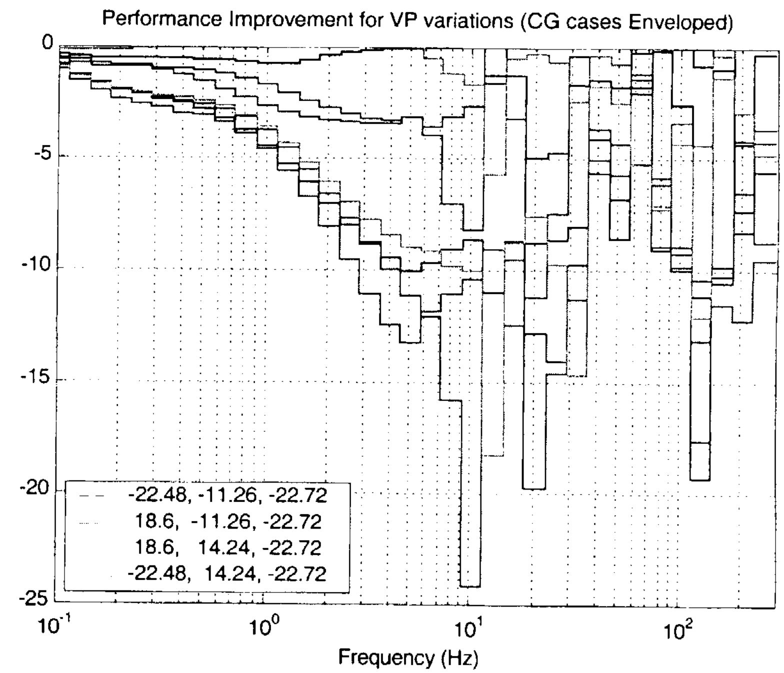
Isolation Improvement At Verification Points (VPs) CG Cases Enveloped, Flex Body , Stiffness Case 3

ARIS Active Rack Isolation System

Top Verification Points



Bottom Verification Points



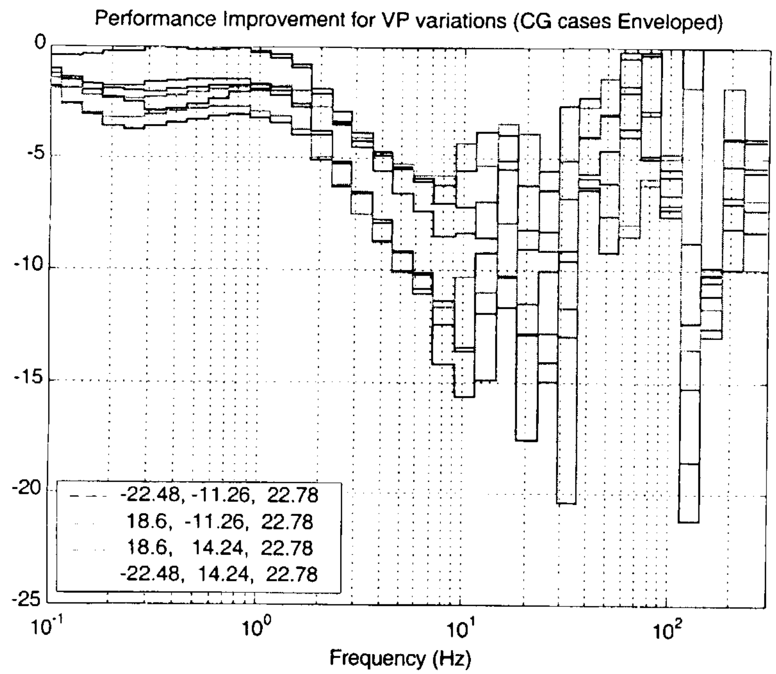
- Isolation is generally better at the top (away from umbilicals), but performance is dependent on CG location.

BOEING
PHANTOM WORKS

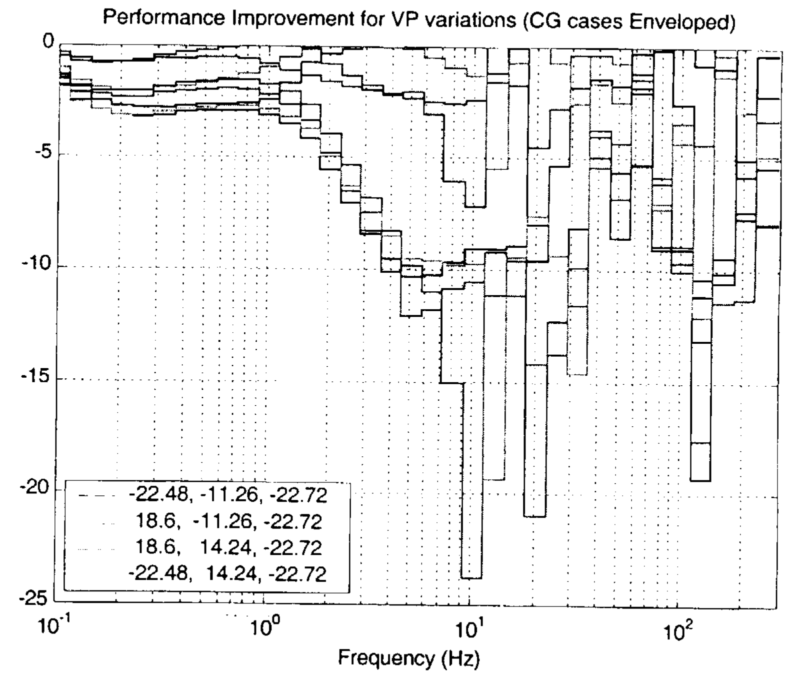
Isolation Improvement At Verification Points CG Cases Enveloped, Flex Body, Stiffness Case 5

ARIS Active Rack Isolation System

Top Verification Points



Bottom Verification Points



- Stiffness variation has some impact below 10 Hz. Trends remain.

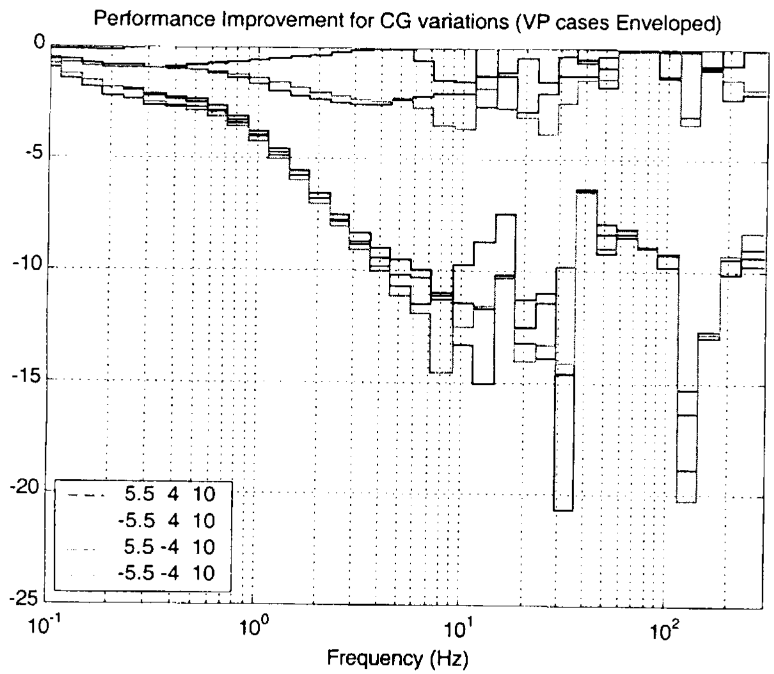
7

PHANTOM WORKS

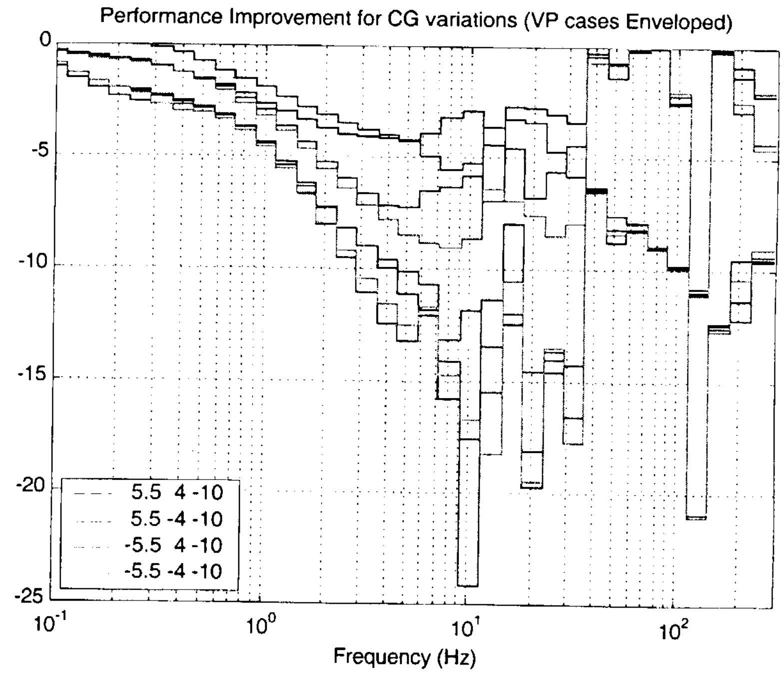
Isolation Improvement For CG locations
VP Cases Enveloped, Flex Body , Stiffness Case 3

ARIS Active Rack Isolation System

Top CG Locations



Bottom CG Locations



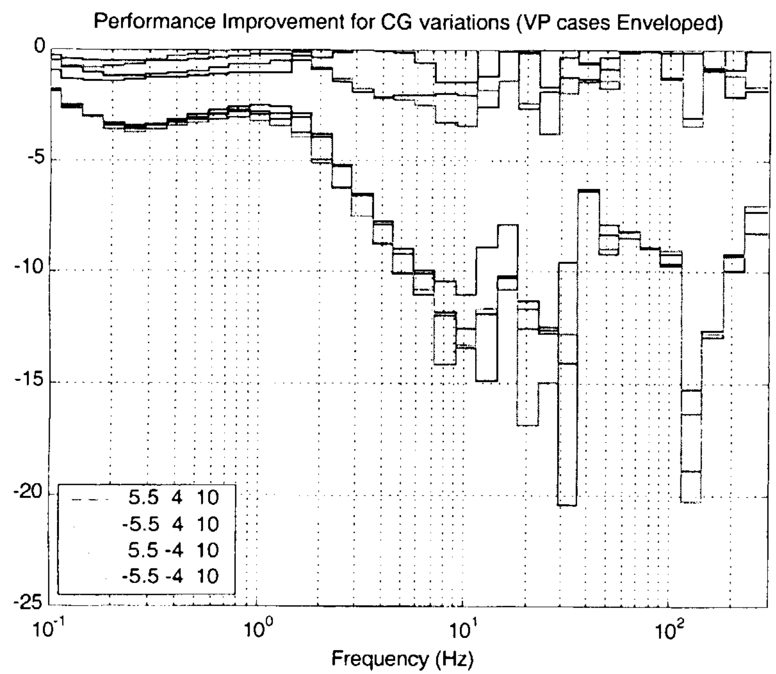
- Isolation is generally better with the CG lower in the rack (closer to umbilicals), but performance is dependent on verification location.

BOEING
PHANTOM WORKS

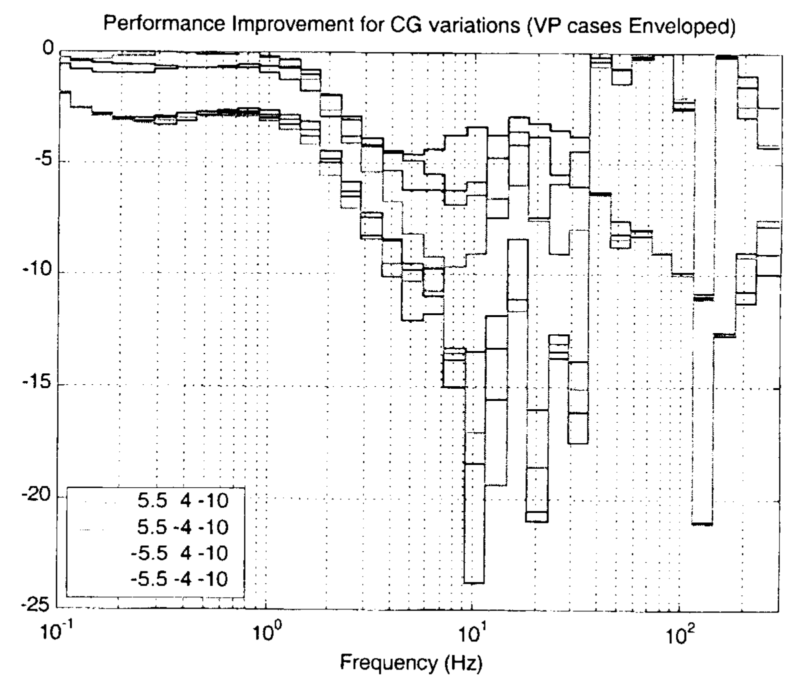
Isolation Improvement For CG locations VP Cases Enveloped, Flex Body , Stiffness Case 5

ARIS Active Rack Isolation System

Top CG Locations



Bottom CG Locations



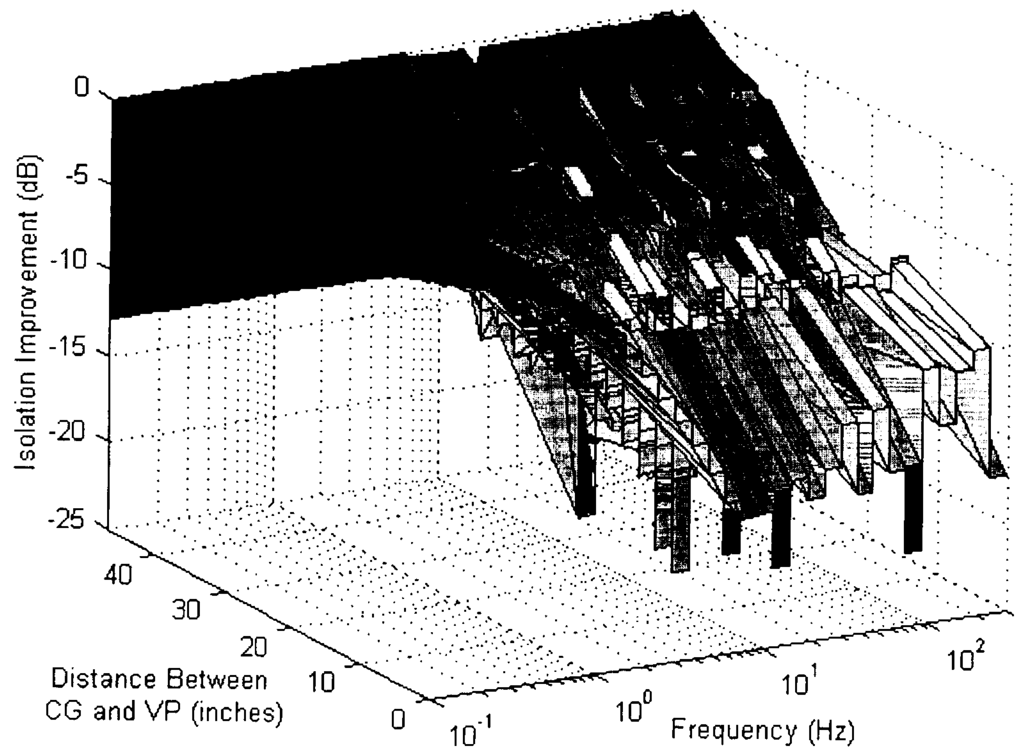
- Stiffness variation has some impact below 10 Hz. Trends remain..

9

BOEING
PHANTOM WORKS

Isolation Versus Distance Between The CG & VP, Rigid Body , Stiffness Case 3

ARIS Active Rack Isolation System



- Better to have microgravity payload near CG (rigid body considerations only)

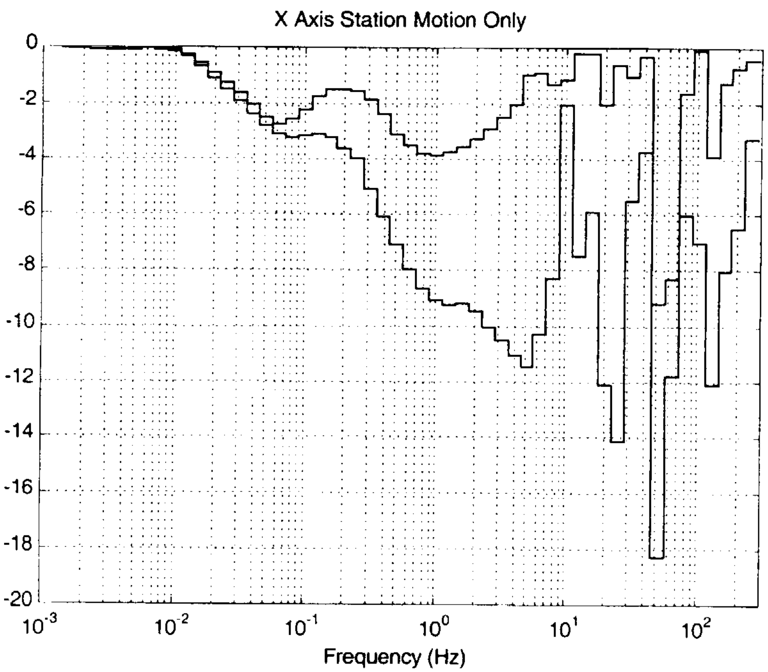
10

PHANTOM WORKS

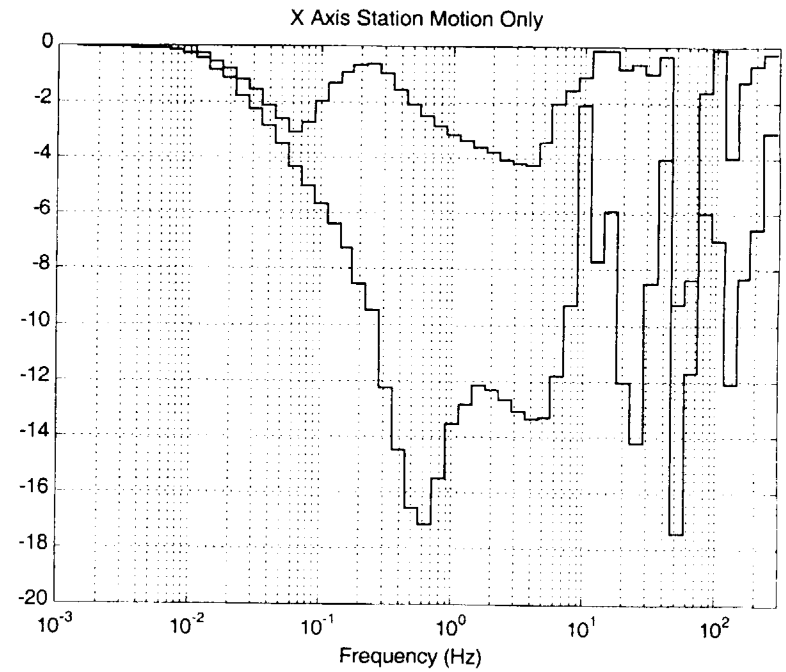
X Axis Versus Worst Input Direction Isolation, Envelope Over All CG and VP variations, Flex Body

ARIS Active Rack Isolation System

Stiffness Case 3



Stiffness Case 5



- Isolation improvement trend increases with frequency up to 5 Hz
- Response above 5 Hz dependent on umbilical and rack dynamic response

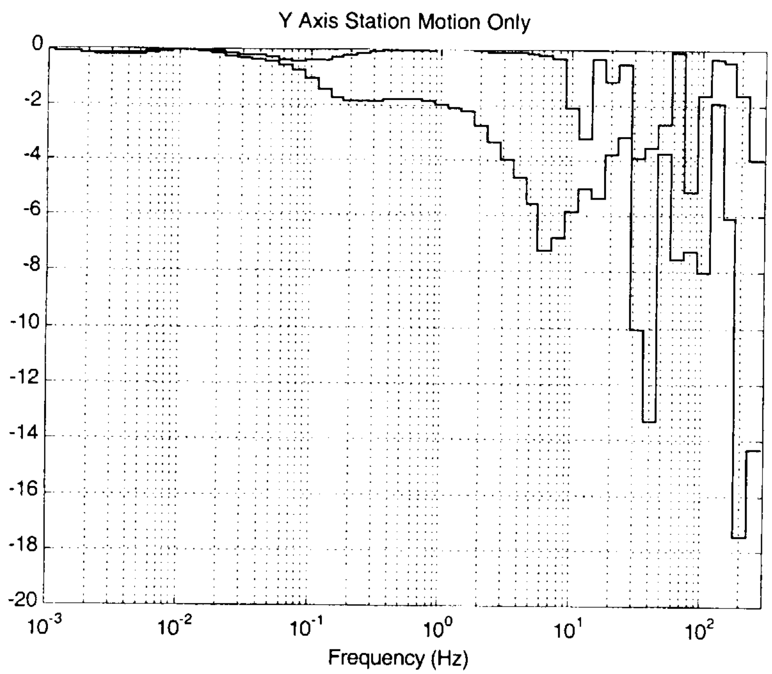
11

PHANTOM WORKS

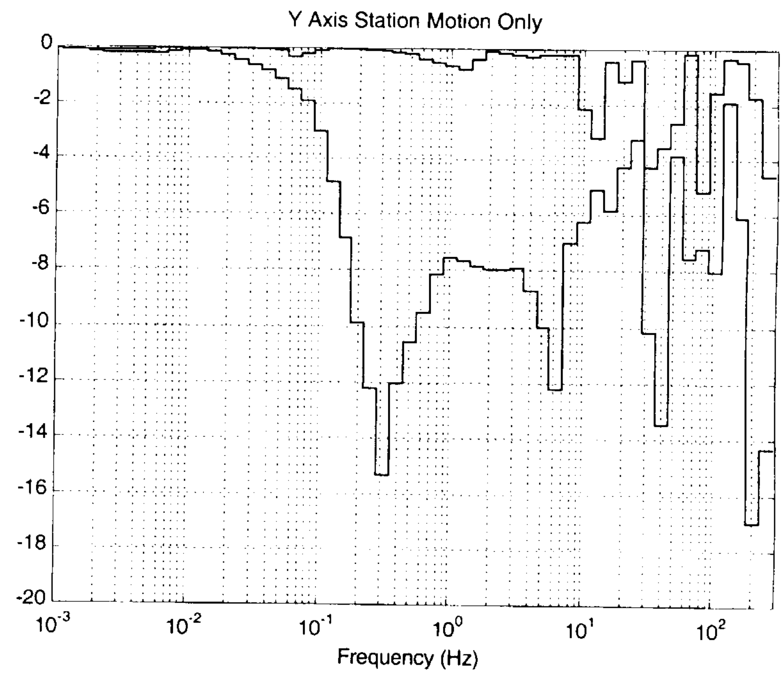
Y Axis Versus Worst Input Direction Isolation, Envelope Over All CG and VP variations, Flex Body

ARIS Active Rack Isolation System

Stiffness Case 3



Stiffness Case 5



- Umbilicals in Y and Z directions are twice as stiff as X direction
- Improvement strongly dependent on CG, VP, and stiffness variations

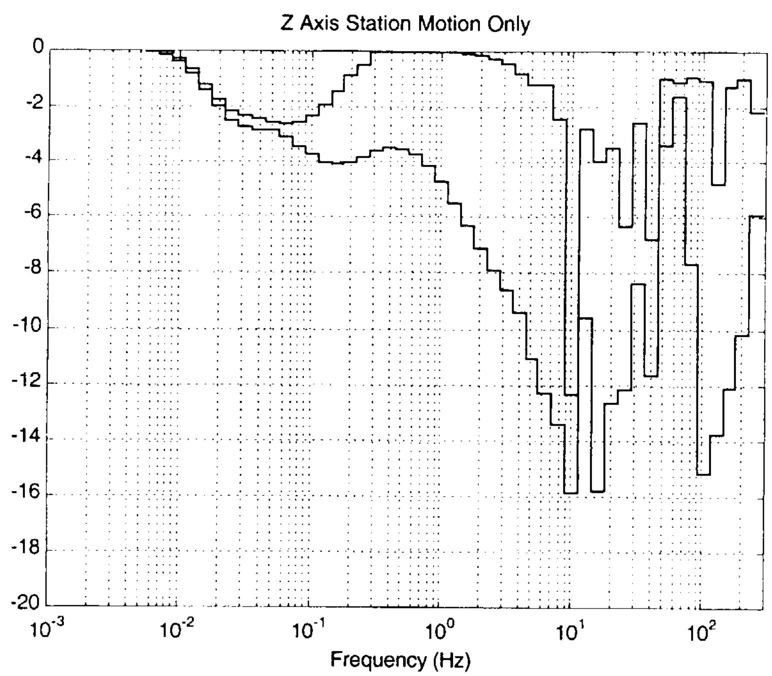
12

BOEING
PHANTOM WORKS

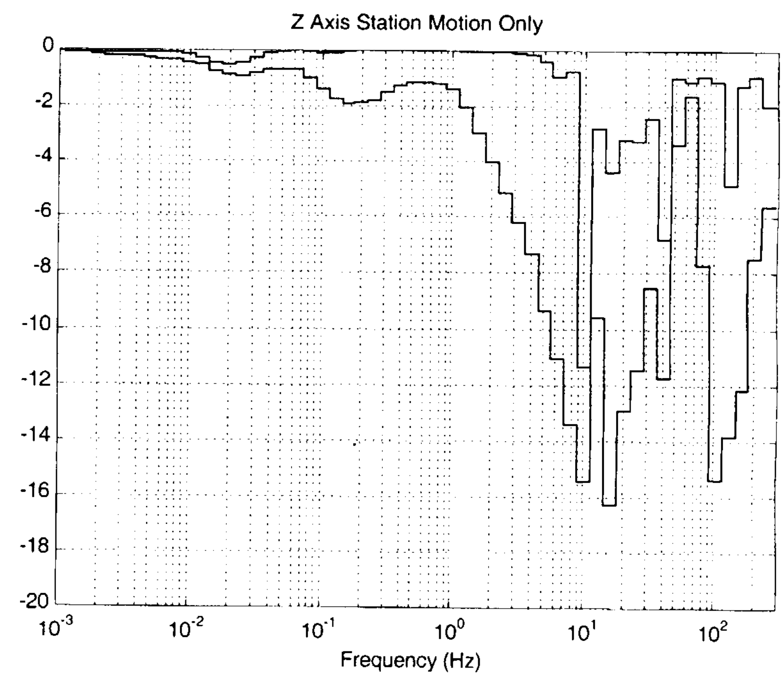
Z Axis Versus Worst Input Direction Isolation, Envelope Over All CG and VP variations, Flex Body

ARIS Active Rack Isolation System

Stiffness Case 3



Stiffness Case 5

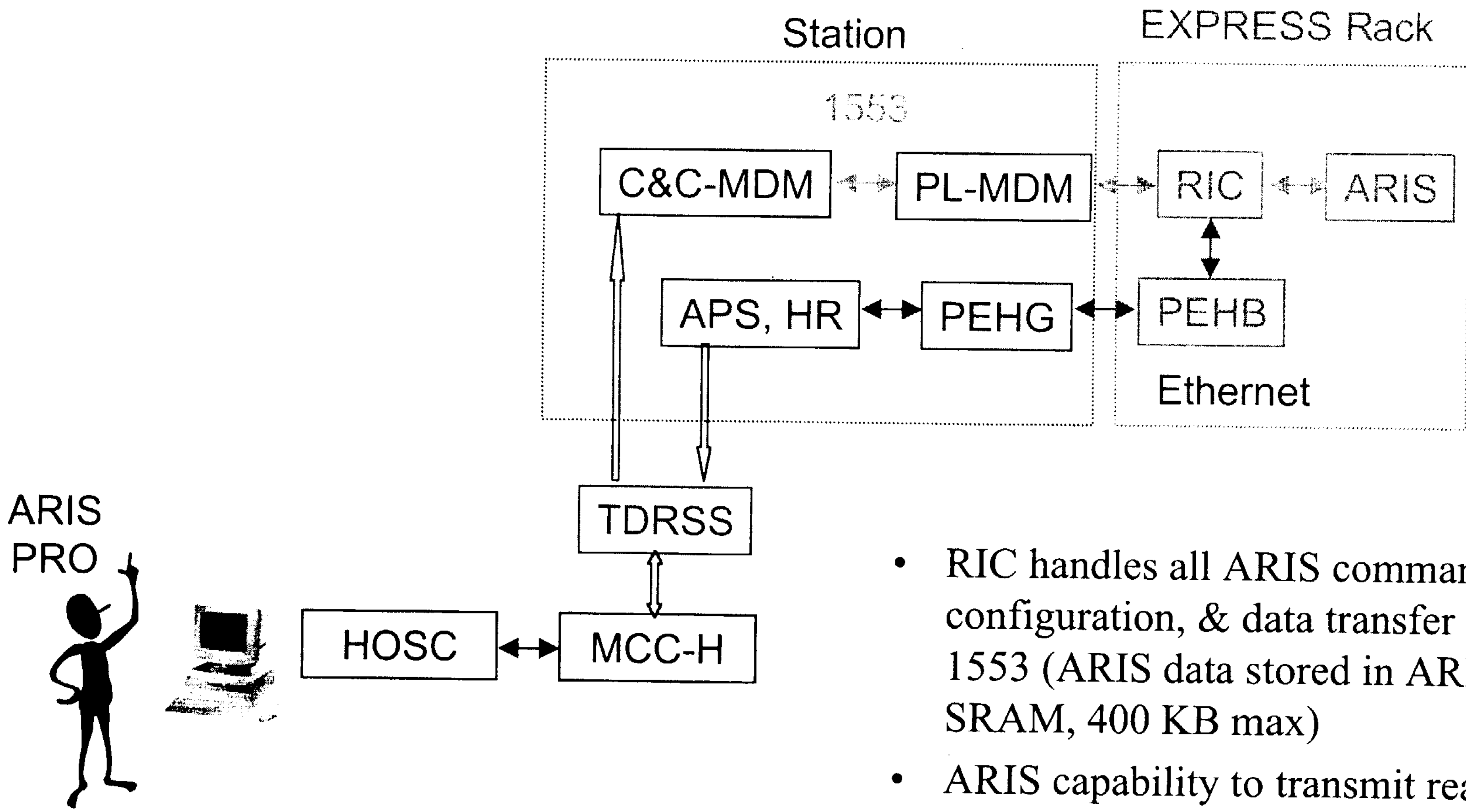


13

PHANTOM WORKS

ARIS Command & Data Handling Configuration

ARIS Active Rack Isolation System



- RIC handles all ARIS command, configuration, & data transfer via 1553 (ARIS data stored in ARIS SRAM, 400 KB max)
- ARIS capability to transmit real time data over 1553 not utilized

14

Buffer Data Available

- Data can be collected from within the I/O Processor (IOP), the Control Processor (CP), or the Test Point Processor (TP). 1 ms data can be collected from Channel #2 only.

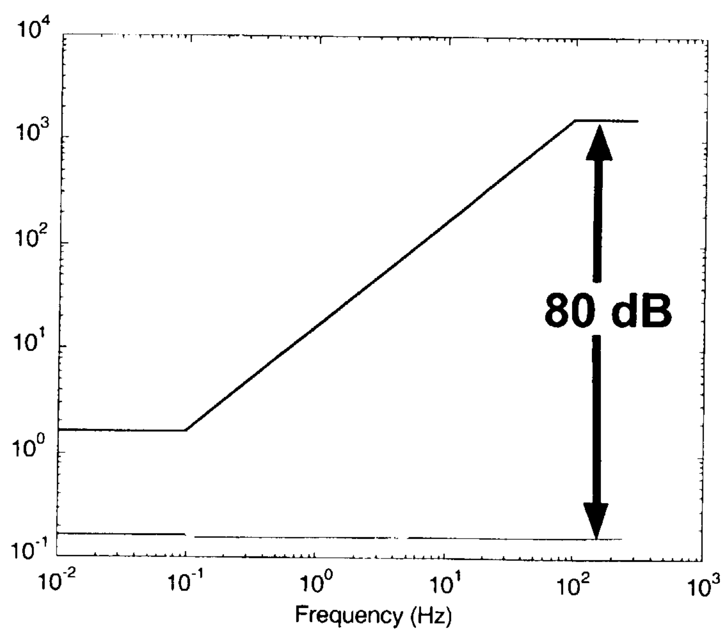
IOP_Data	CP_Data	TP_Data
8 Positions	6-DOF Positions	accel filter1[6]
9 Accel Ch. 1	6-DOF Accels	accel filter2[6]
9 Accel Ch. 2	6-DOF Force	accel filter3[6]
9 Accel Temps	6-DOF Accel In	accel filter4[6]
	6-DOF Accel Out	accel filter5[6]
	6-DOF Position In	accel filter6[6]
	6-DOF Position Out	accel filter7[6]
	6-DOF Stiffness	accel filter8[6]
	6-DOF Anti-bump	pid derivative[6]
	8 Force Comands	pid sum1[6]
	8 Actuator Commands	pid filter1[6]
	8 Actuator Currents	pid integral[6]
		pid sum2[6]
		stiffness filter[6]
		ab filter1[6]
		ab filter2[6]
		ab filter3[6]

Maximum File Size = 100,000 Words

ARIS Test Buffer Limitation

Buffer not designed to obtain low frequency isolation data during active mode.

- Maximum test duration ~ 18 seconds if only Channel #1 accelerations are collected.
- Recommend 16 cycles to measure performance, so 1600 seconds of test data required to measure down to 0.01 Hz.

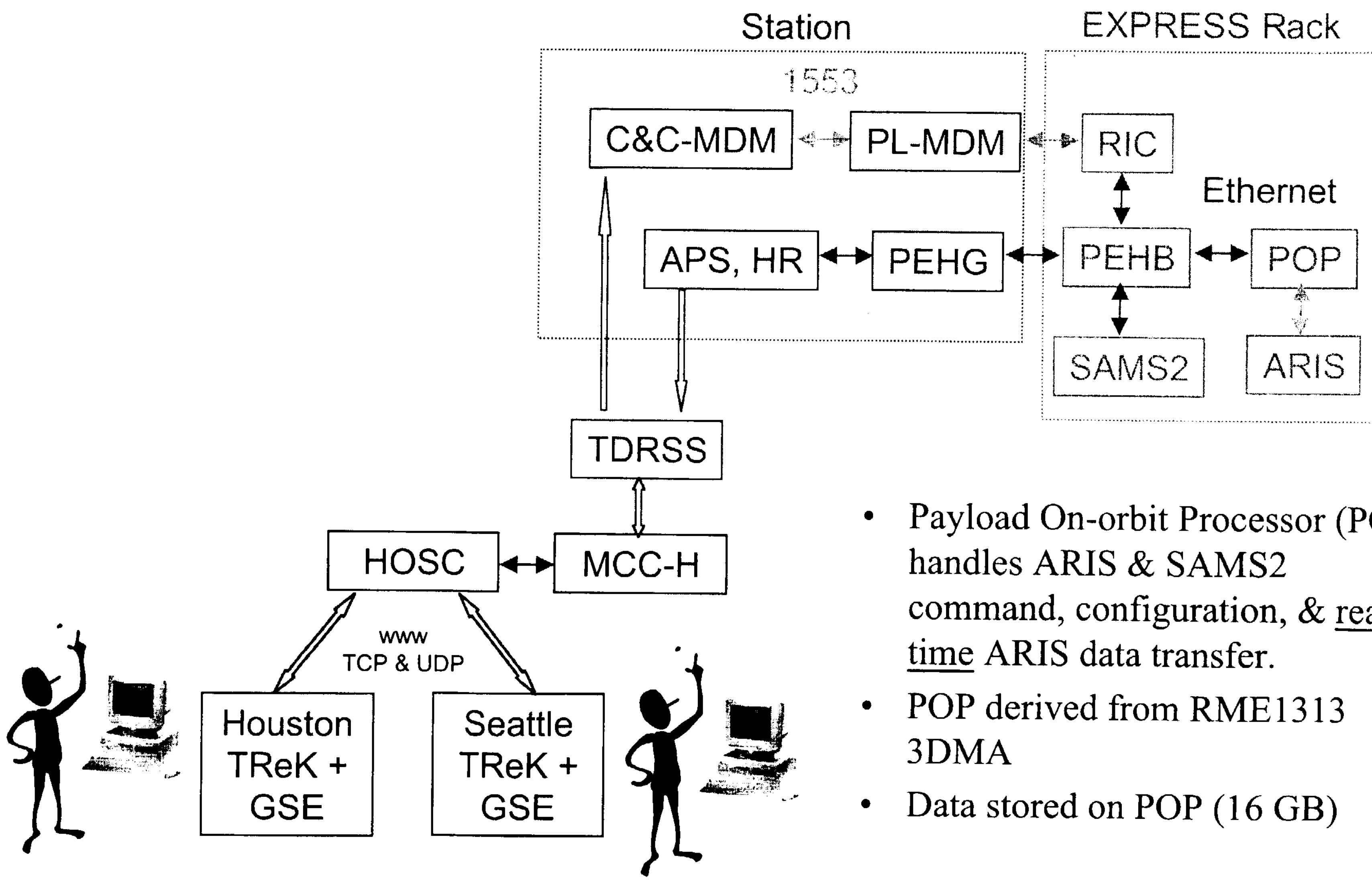


Can not decimate data without aliasing. If rack acceleration magnitude equals the micro-gravity requirement, then at least 80 db anti-aliasing attenuation is needed to keep aliased data an order of magnitude below the requirement.

BOEING
PHANTOM WORKS

ARIS ICE
Command & Data Handling Configuration

ARIS Active Rack Isolation System



- Payload On-orbit Processor (POP) handles ARIS & SAMS2 command, configuration, & real time ARIS data transfer.
- POP derived from RME1313 3DMA
- Data stored on POP (16 GB)

17

ARIS ISS Characterization Experiment (ARIS-ICE) Configuration Solution

- POP contains a powerful test and C&DH software. The POP,
  - Can receive korn shell commands from GSE (Runs QNX Operating System)
  - Runs a high level scripting tool command language (Tcl)
  - Runs technical computing language RLAB (like Matlab)
  - Issues ARIS configuration and data collection commands
  - Issues SAMS2 configuration and data collection commands
  - Stores ARIS and SAMS2 data
  - Sends "screen prints" as telemetry
  - Provides ARIS and POP Health & Status to EXPRESS RIC
  - Enables file transfers via EHS scripts and commands

Data Available In Real Time

- Every sample of data must be requested. Transmission rates are controlled, and potentially limited by the requesting computer.

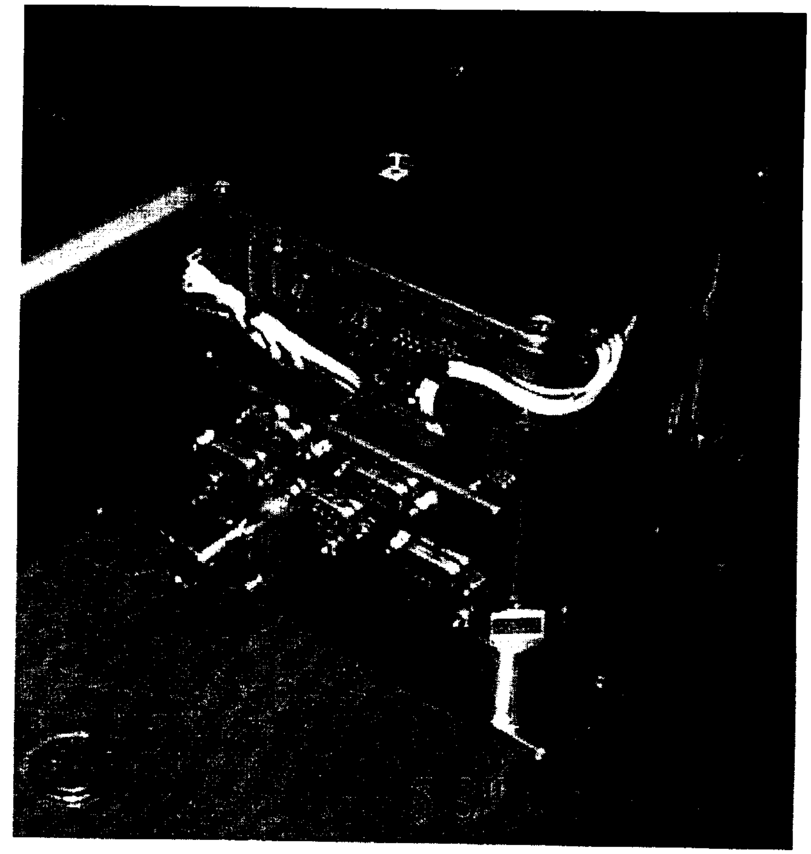
Transmit Message	**SA**	**Data Words**
ARIS Status	1	30
ARIS Active BIT Data	2	14
ARIS Passive BIT Data	3	32
ARIS Actuator Positions	4	11
ARIS Actuator Currents	5	11
ARIS PWM Commands	6	11
ARIS Anti-Bump Accels	7	9
ARIS Temps	8	15
ARIS Active Control Parameters	9	32
ARIS Position Hold Control Parameters	10	32
ARIS Configuration Parameters	11	32
ARIS Accel Channel 1	12	12
Buffer Download	13	32
ARIS Accel Channel 2	14	12
Accel/Position Data	30	19

Maximum data rate = 30 words per ms

Mini-POP Concept

Build Mini-POP using PC/104 architecture to support non-EXPRESS users

- Recommend SAMS-FF Control & Data acquisition Unit (CDU) design
  - saves cost and is small
  - Uses 486 so compatible with POP
  - STS-107 design will have ethernet IF
  - Both hard drive (larger capacity) and nonvolatile FLASH memory (more rugged, no moving parts) are used for data storage.



POP Utilization
For Non-EXPRESS racks

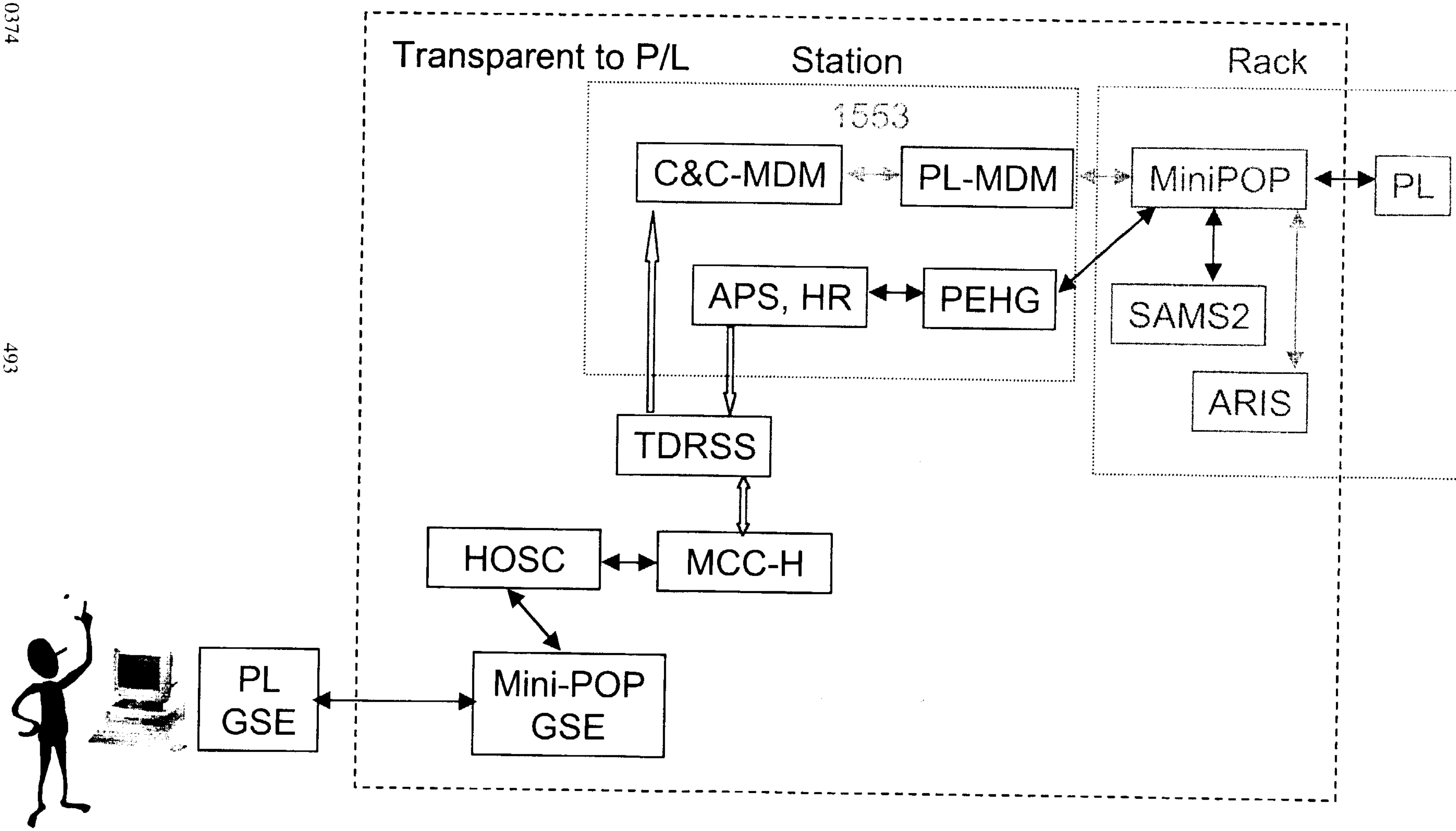
Options for Non-EXPRESS users

- Option 1: Utilize mini-POP to handle ARIS and SAMS2 interface functions
  - PL required to perform RIC functions by interfacing to MDMs and mini-POP
- Option 2: Utilize mini-POP to perform RIC functions
  - PL only required to interface to mini-POP
- Option 3: Utilize mini-POP to perform RIC functions and build GSE so that ISS systems are transparent to PL

PHANTOM WORKS

Option 3
Command & Data Handling Configuration

ARIS Active Rack Isolation System



Active Rack Isolation System ISS Characterization Experiment

Overview

August 31, 1999

BOEING

James L. Allen
Glenn Bushnell
Ian Fialho

ARIS ICE Status

- ARIS-ICE DD250: 7/14/00
- KSC On-Dock: 7/24/00
- KSC Off-line testing: 7/26/00
- KSC Turnover: 7/31/00
- 6A Launch: 4/19/01

Outline

BOEING

- High-Level ARIS-ICE Objectives
- Experiment Overview
- Hardware Configurations
- Shaker Performance
- Detailed Tests, Methods, and Objectives
- Generic Test Sequences
- On-Orbit Operations and Mission Timeline

ICE High-Level Objectives

BOEING

- Characterize on-orbit isolation performance for simulation, analysis, and (simulation model) validation purposes on an ARIS production unit.
- Test and evaluate the design modifications made as a result of RME 1313 (STS-79) conclusions.
- Obtain constraint information on payload devices in an ARIS rack, as well as disturbances induced by ARIS into non-isolated racks.
- Gain on-orbit experience with nominal operations of ARIS.
- Identify procedures for preflight readiness checkouts.
- Evaluate ARIS on-orbit maintenance tasks.
- Evaluate/Validate ground operation interfaces and procedures.
- Evaluate crew/software interfaces.

Hardware Summary

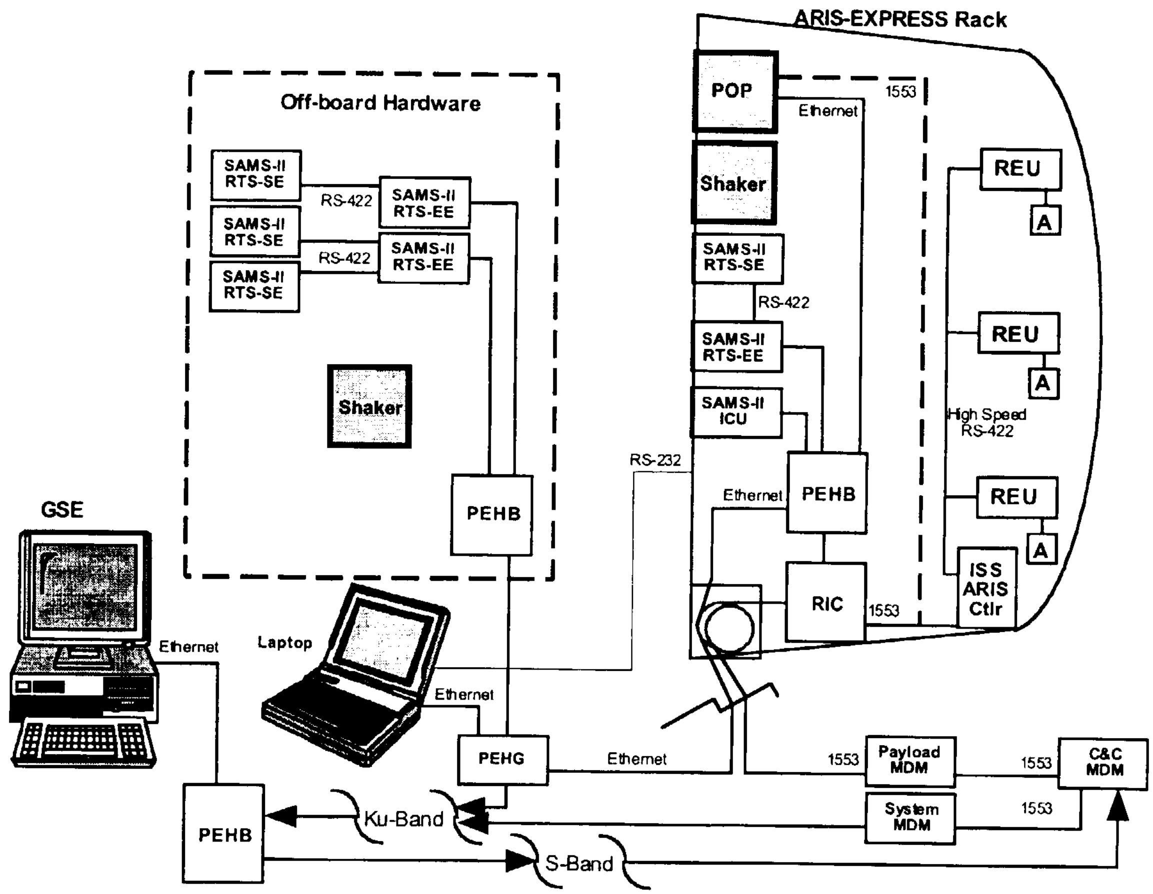
BOEING

- **Major components**
  - **Payload On-orbit Processor (POP) for test execution control and data capture, post-processing and downlink.**
    - POP is modified 3DMA unit that flew on STS-79. Only minor modification.
  - **Relocatable Shaker to provide known, measurable vibration levels at station (off-rack) and rack (on-rack) interfaces.**
  - **Laptop Support Assembly to minimize impact of crew laptop operations on ARIS isolation performance.**
  - **Alternate Power Umbilical Sets to characterize on-orbit performance of various power umbilical configurations.**

- **Supporting components**
  - **EXPRESS rack - Provide power, data and thermal resources**
  - **ARIS - Provide on-rack acceleration measurements**
  - **SAMS-2 - Provide off-rack acceleration measurements**
  - **MAMS - Provide station quasi-steady measurements**

ARIS-ICE Interface Diagram

BOEING



08/31/99

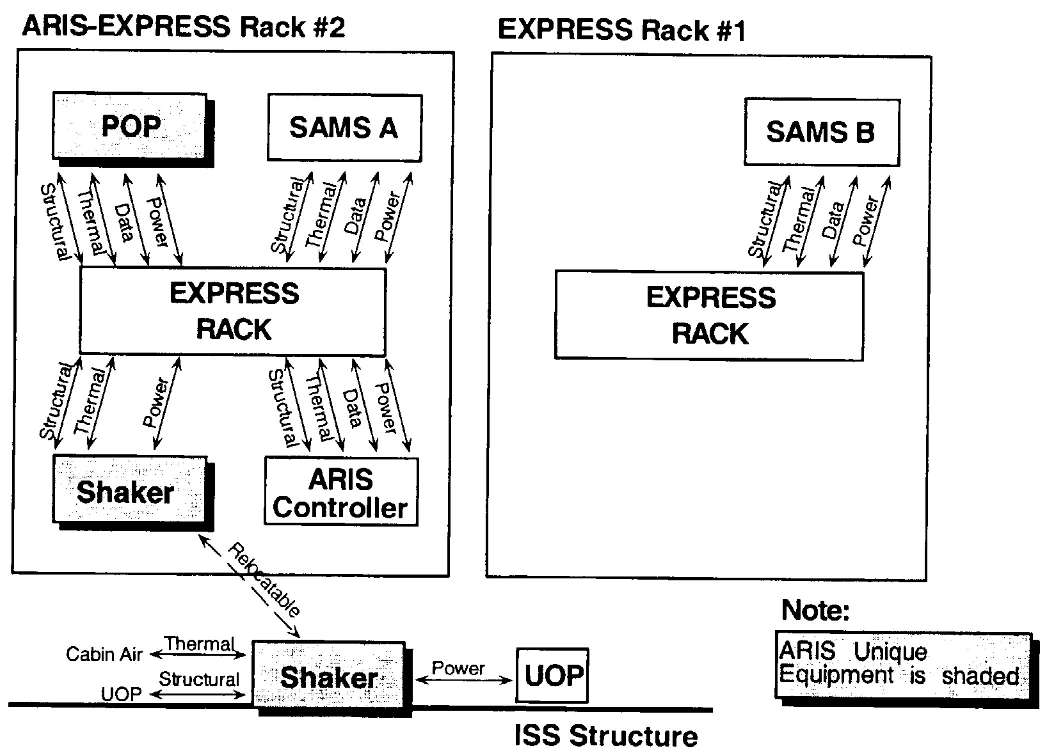
5

ARIS-ICE

ARIS-ICE Interfaces

BOEING

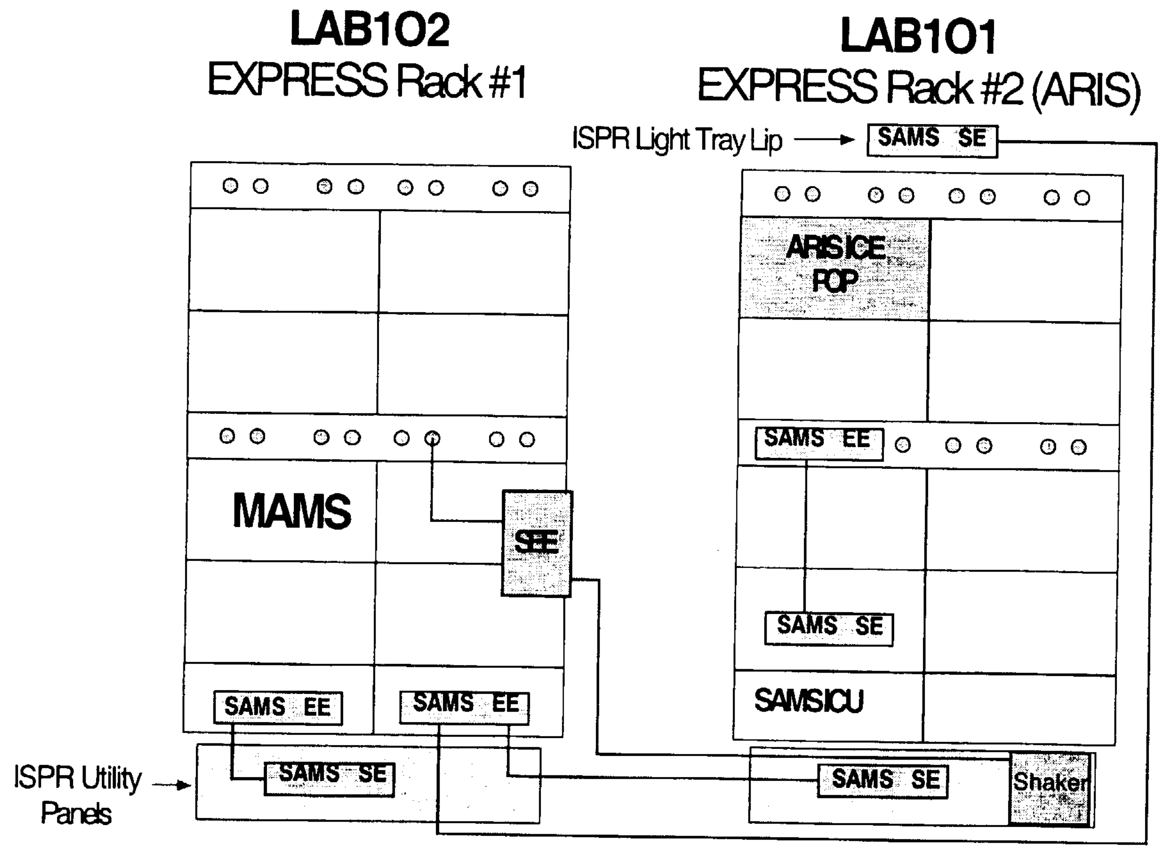
PIDS Figure 3.1.1-4



08/31/99 6 ARIS-ICE

ARIS-ICE Payloads and Rack Layout for Station Shake Tests

BOEING



SEE: Shaker Electronics Enclosure

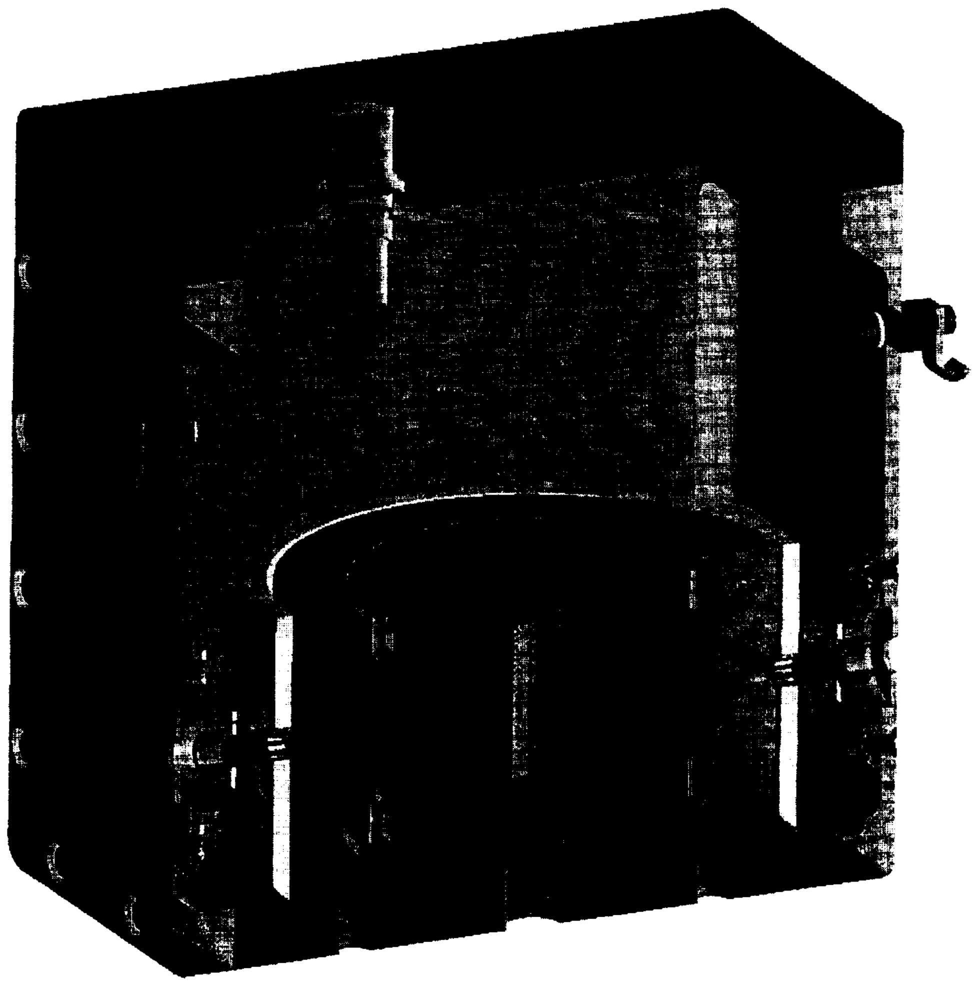
08/31/99

7

ARIS-ICE

Shaker Assembly: Section View

BOEING



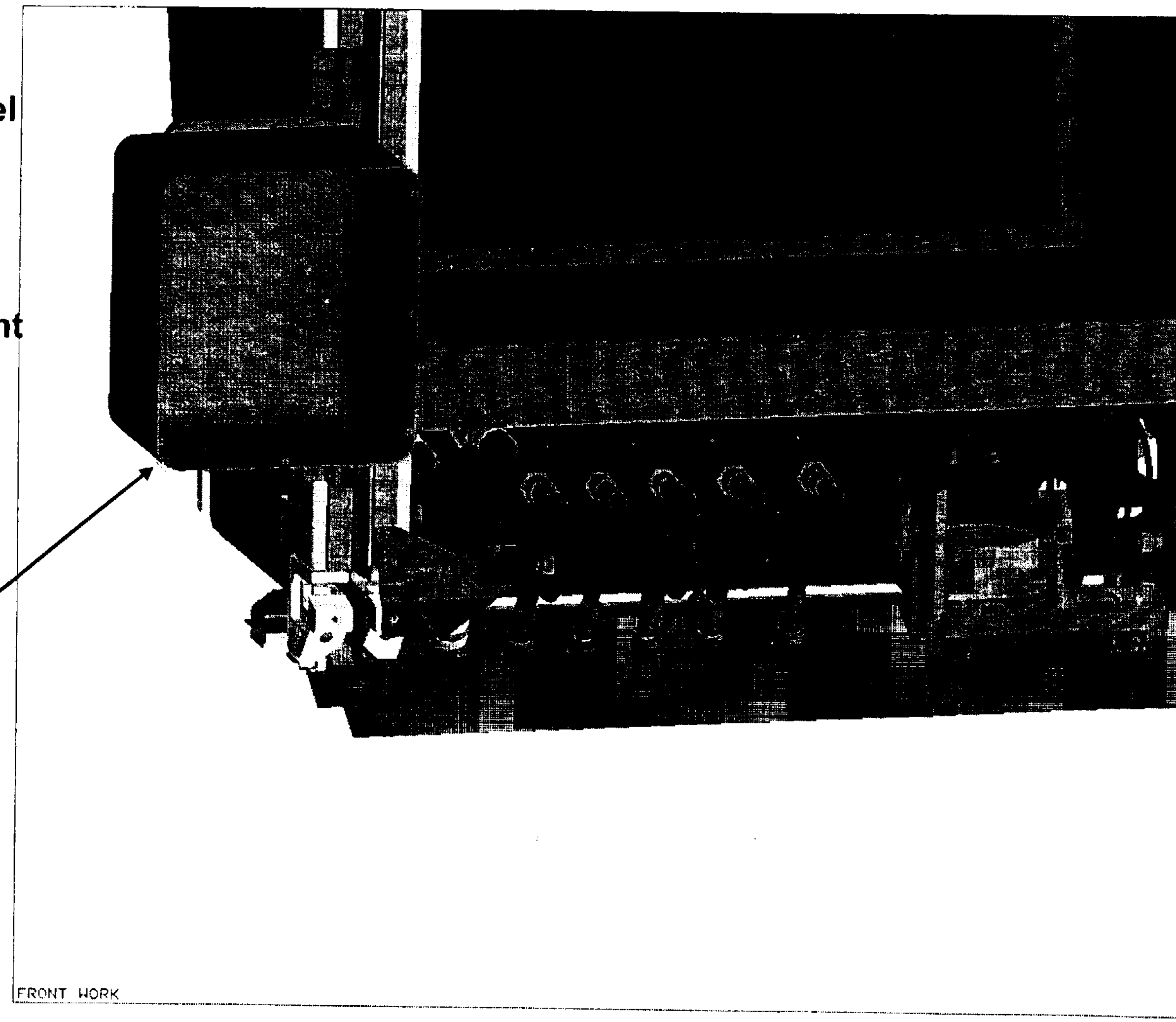
- **Shaker sensitive to Shear loads**
  - **Sleeve to restrain Shaker Proof Mass to .050" rotation**
  - **Hold-down screw to retrain Shaker Proof Mass Axial direction**
    - Screw is captive and spring loaded to resist Shaker induced vibration

Station-Shake Configuration

BOEING

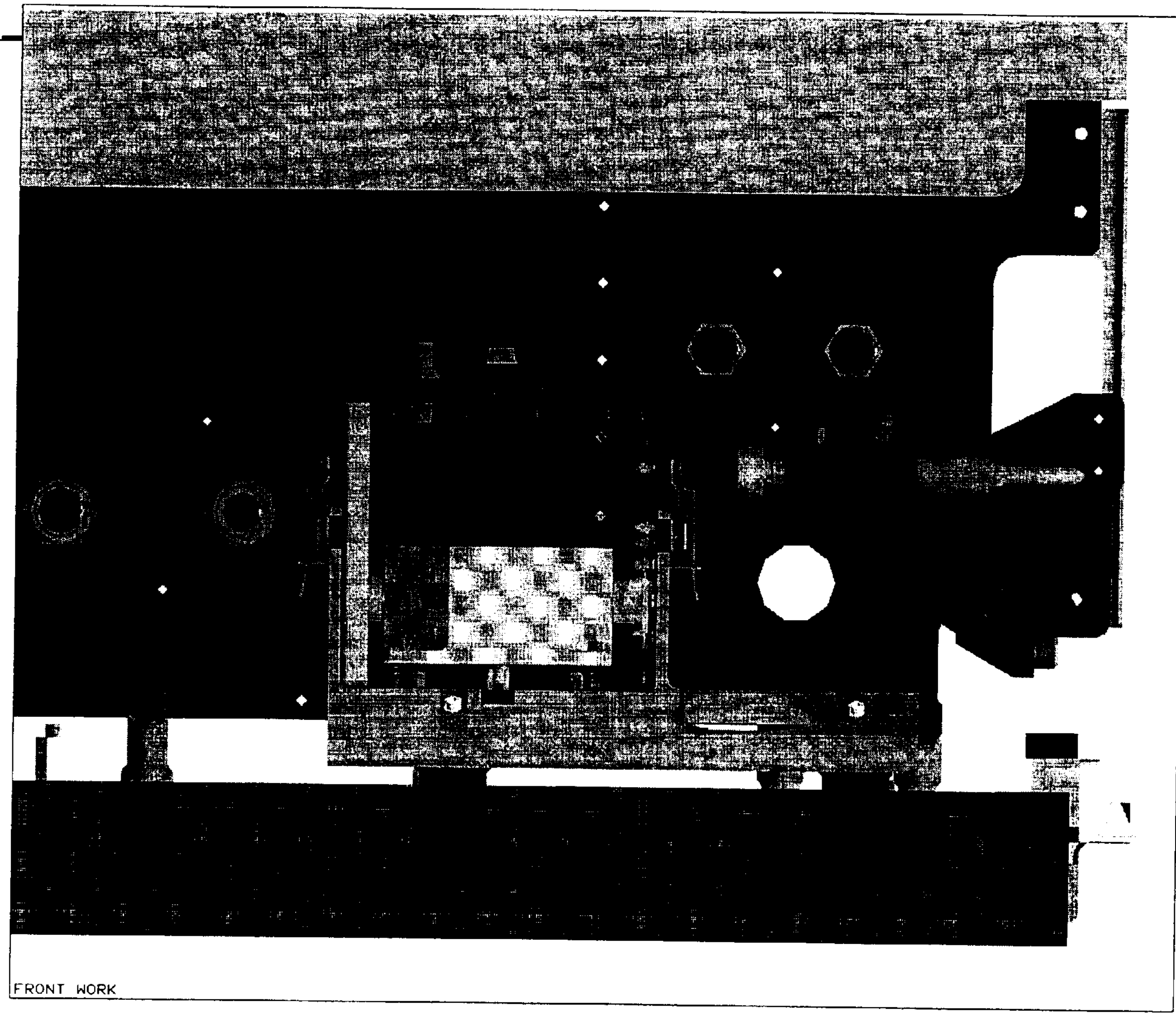
- Shaker mounted to Z-Panel via Low Temp Connector (2x)
- Electronics mounted to adjacent EXPRESS Rack
- Power supplied by adjacent EXPRESS Rack

Electronics
Mounted to
Adjacent
EXPRESS Rack



Station-Mounted Shaker

BOEING



08/31/99

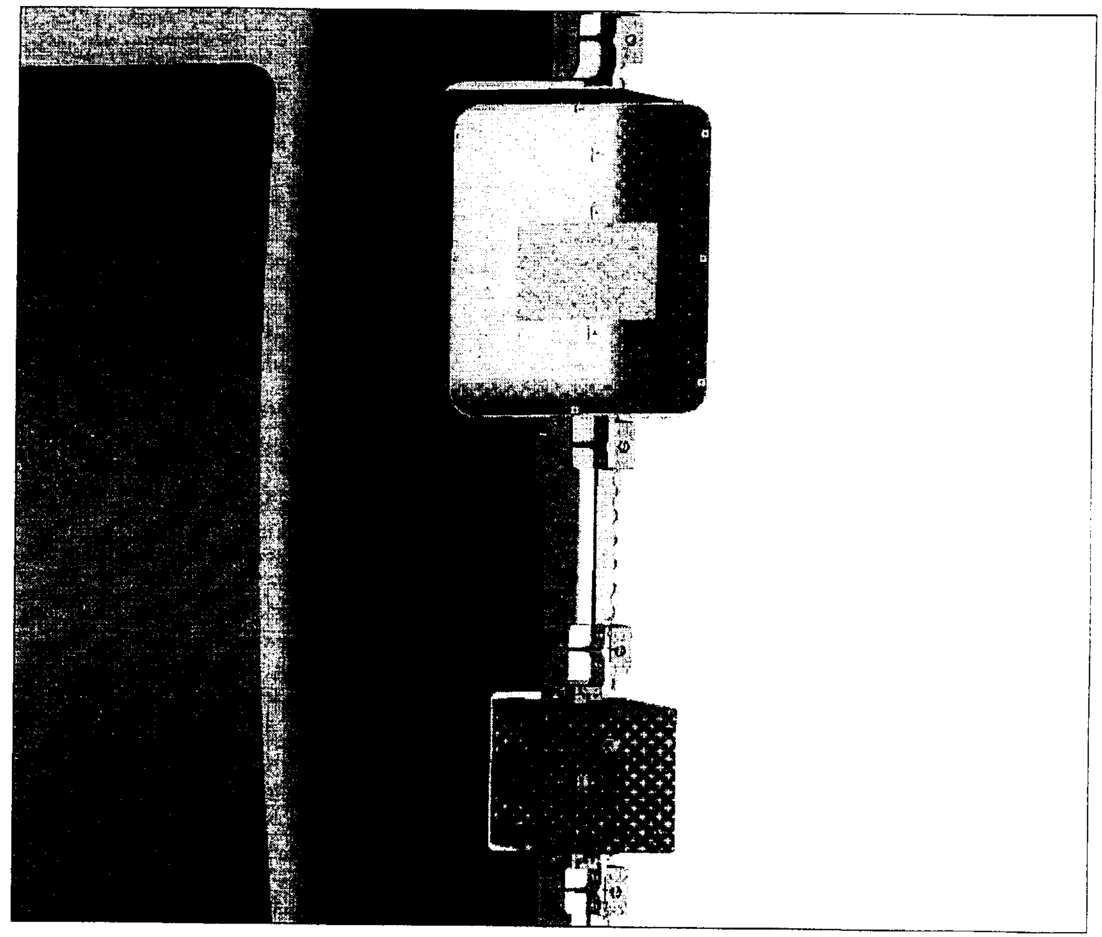
10

ARIS-ICE

Rack-Shake Configuration

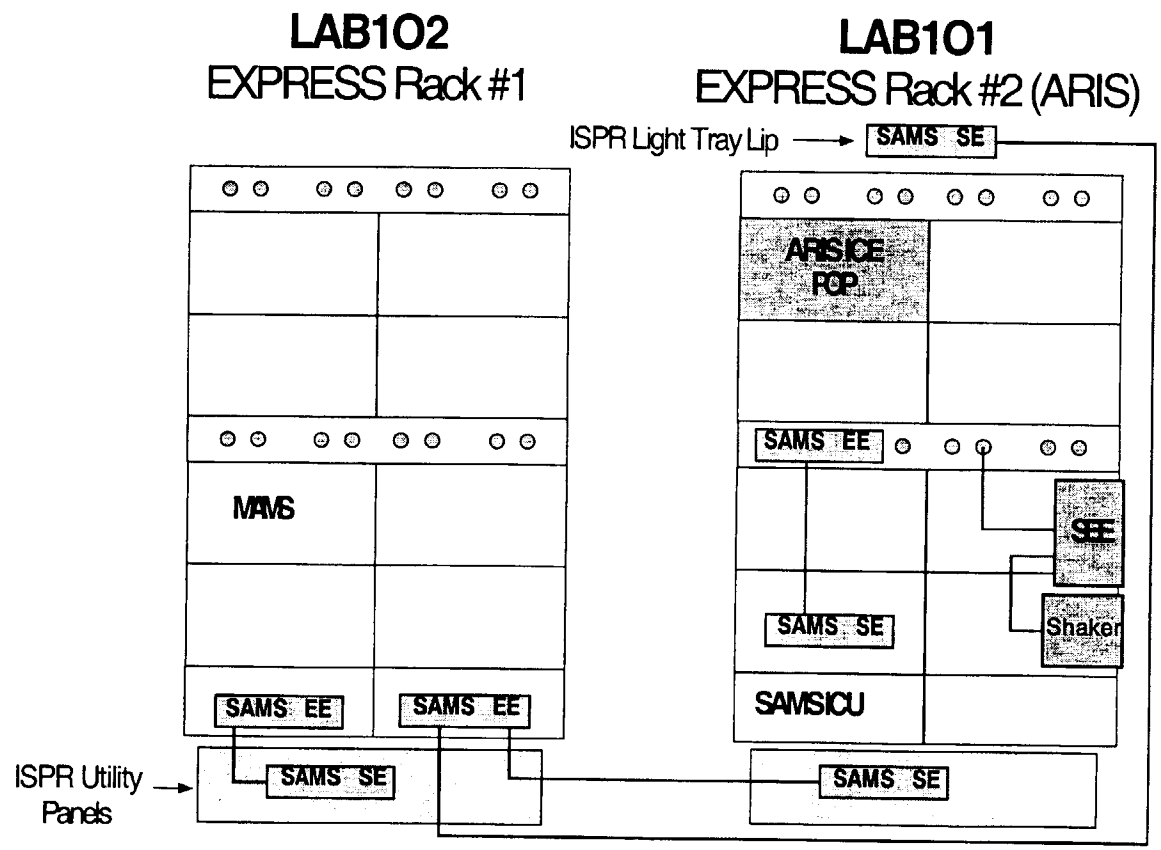
BOEING

- Shaker mounted Seat Track via Extender (2x)
- Electronics mounted to Seat Track via Extender (2x)
- Power supplied by ARIS EXPRESS Rack



ARIS-ICE Payloads and Rack Layout for Rack Shake Tests

BOEING



SEE: Shaker Electronics Enclosure

08/31/99

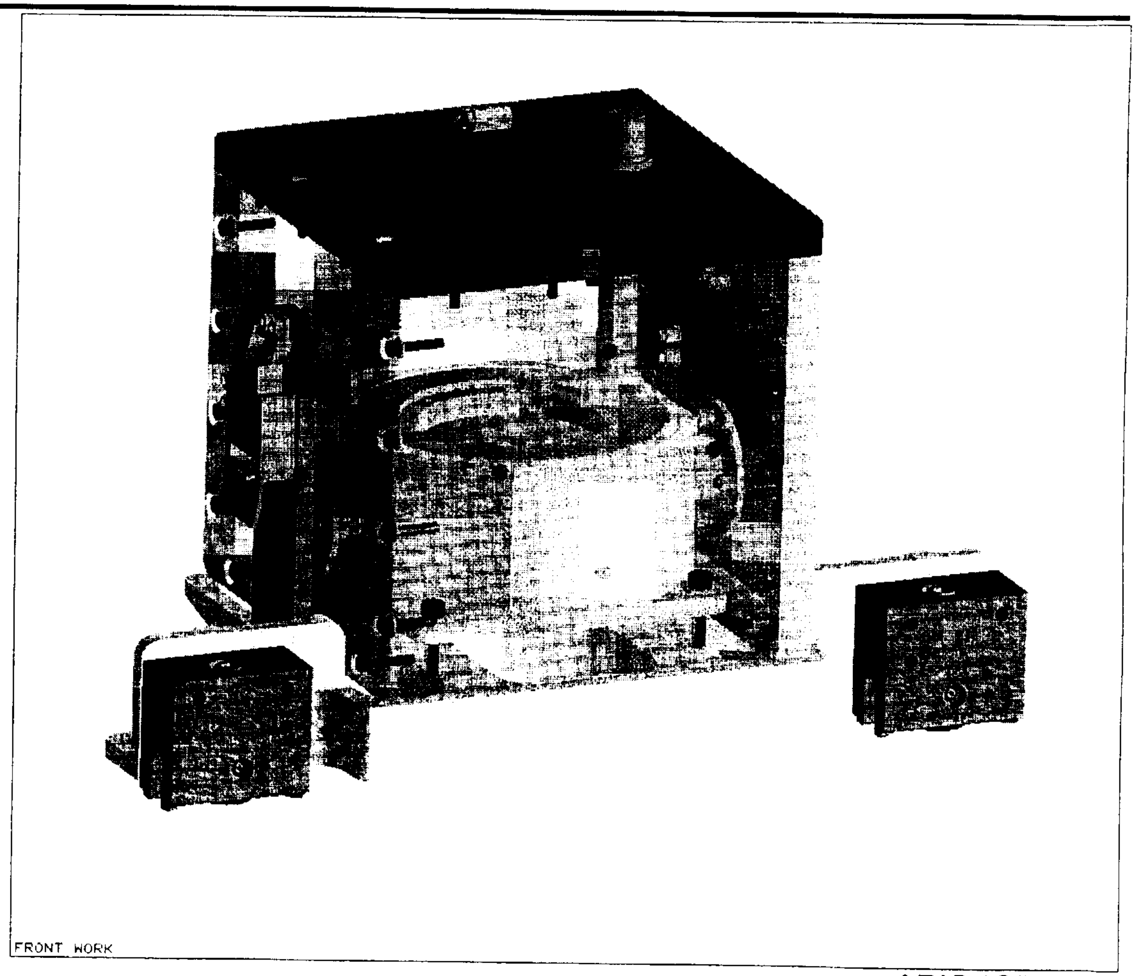
12

ARIS-ICE

Rack-Mounted Shaker Assembly

BOEING

- Shaker will be rotated twice in order to accomplish 3 directions
- Lock-down Screws to be disengaged prior to initial attachment



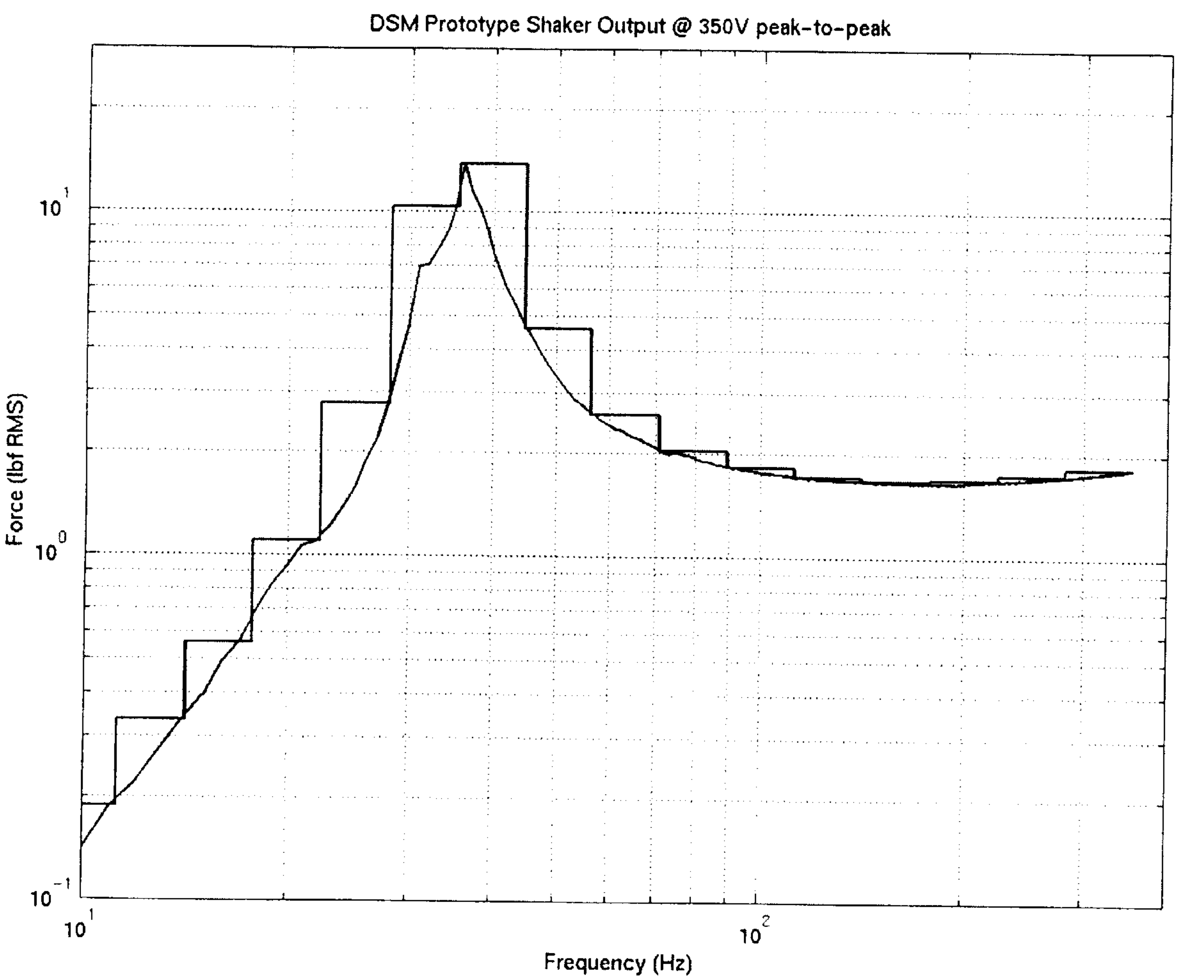
08/31/99

13

ARIS-ICE

Shaker Performance

BOEING

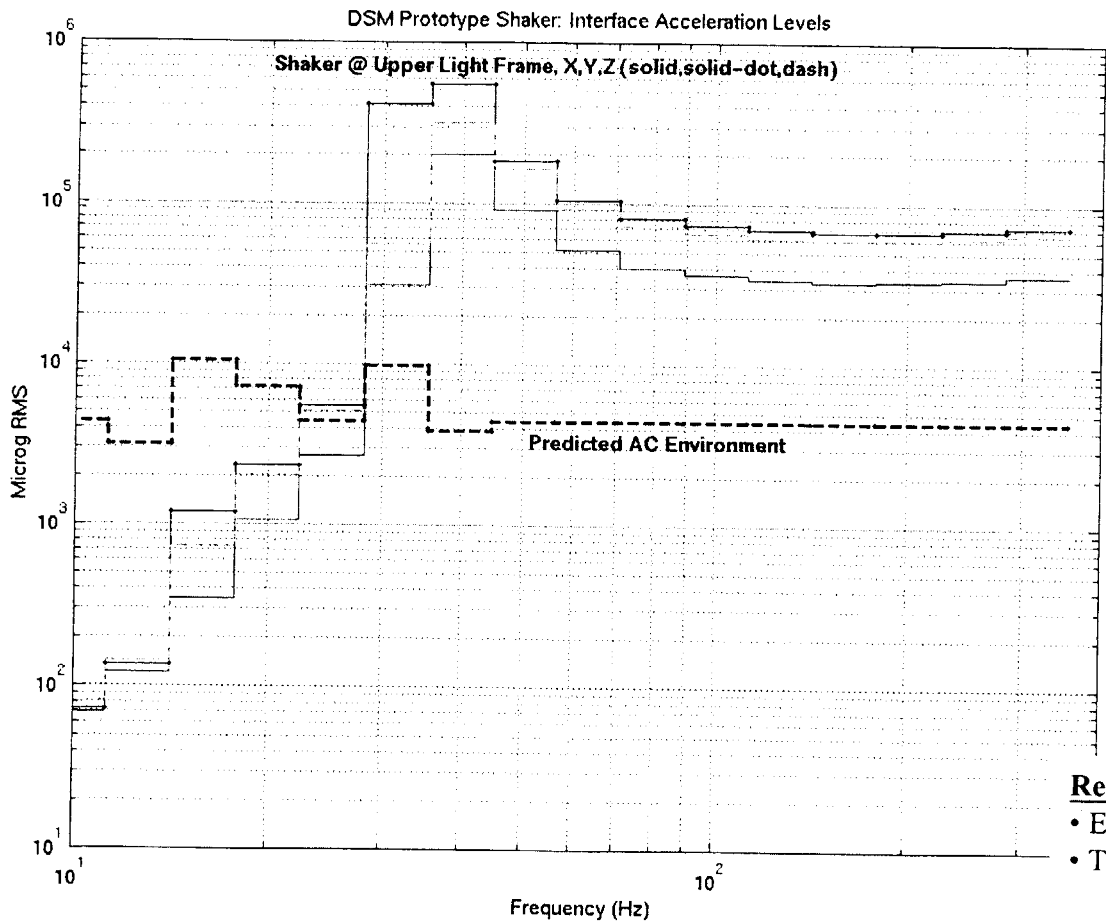


•**Prototype shaker** with 10 lb proof mass
•Resonance Frequency = 34 Hz
•High Frequency Force = 1.7 lbf (RMS)
•Force@ 10 Hz = 0.14 lbf (RMS)

•**Flight shaker** will have 15 lb proof mass
•Resonance Frequency ≅ 28 Hz
•High Frequency Force remains the same
•Force @ 10 Hz ≅ 0.3 lbf (RMS)

Predicted Shaker-Induced Acceleration Environment

BOEING



- Acceleration levels @ 7 ARIS interface points:
  - Upper ARIS Light Frame
  - Isolation Plate Left Side Front/Back
  - Isolation Plate Right Side Front/Back
  - Isolation Plate Back Left/Right

computed using 6A transfer functions

- 6A Model:
  - Integrated model, Z-panel without umbilicals

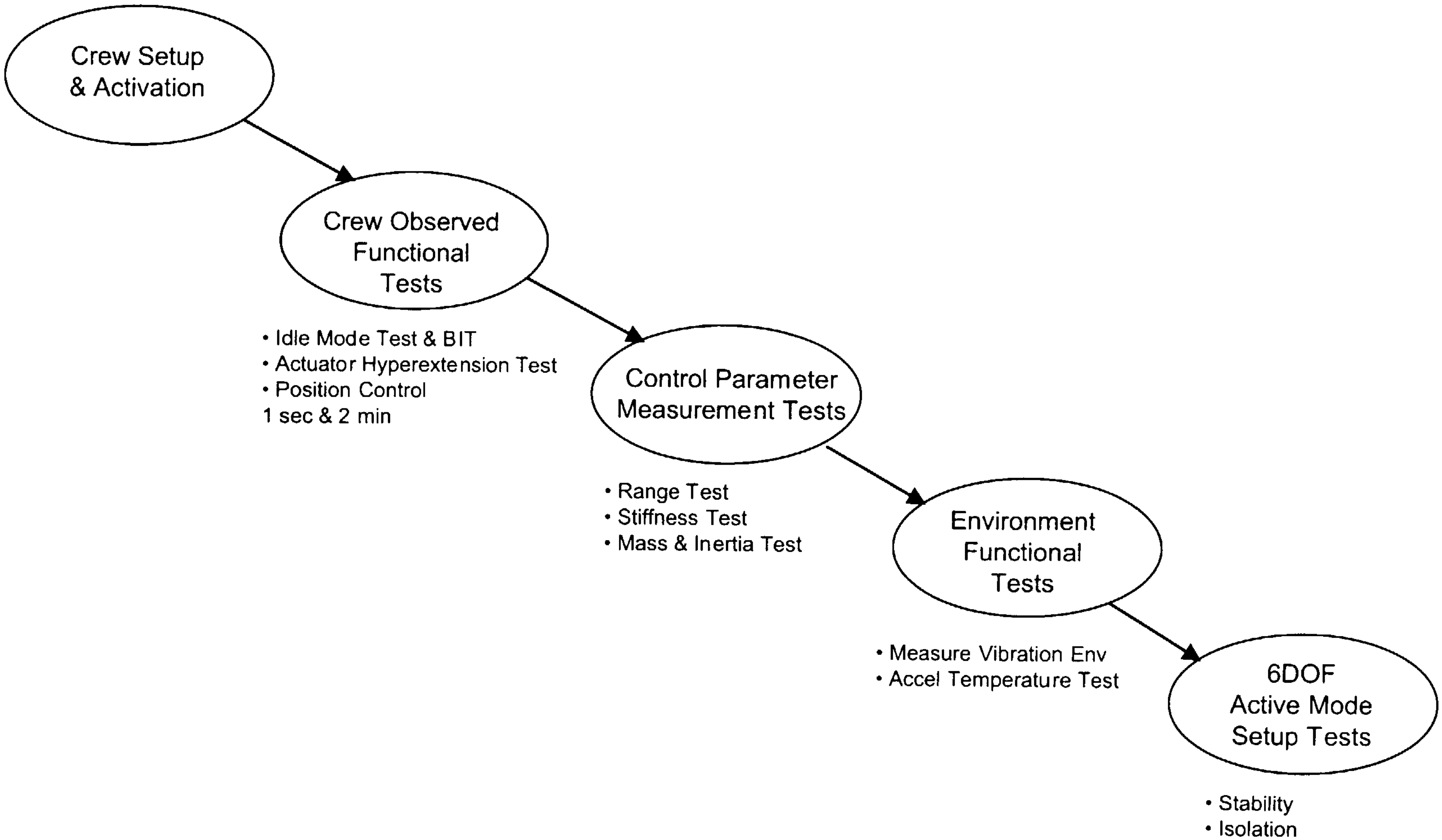
- High acceleration levels achieved above shaker resonance
- Insufficient controlled levels below 20 Hz

Remarks:

- Excessive acceleration levels at shaker resonance
- Two possibilities to reduce resonance peak
  - Open loop notch filter
  - Feedback loop around shaker

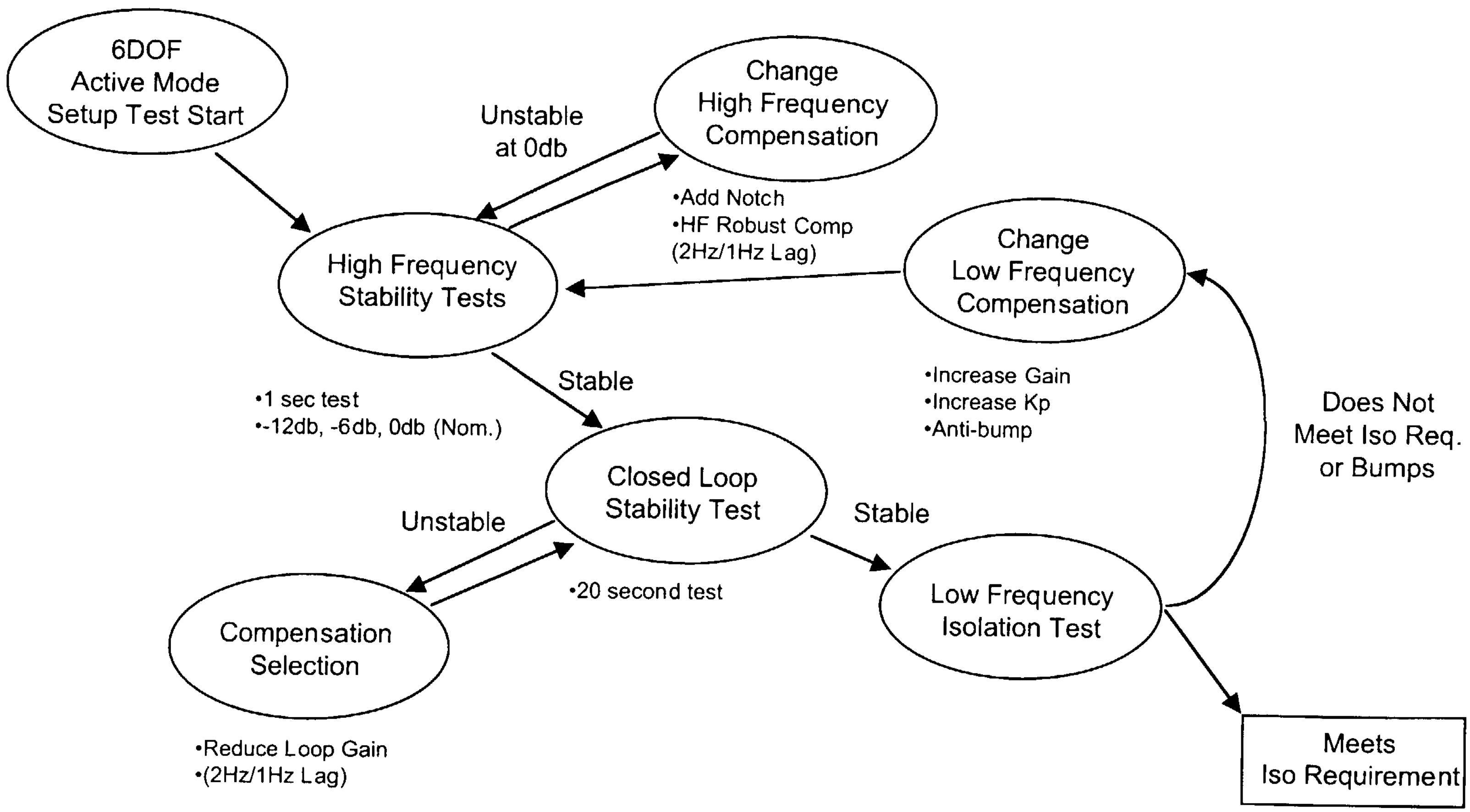
Control Parameter Selection Method

BOEING



6DOF Control Parameter Selection Method

BOEING



08/31/99

17

ARIS-ICE

Mission Success Criteria

BOEING

- Minimum Success Criteria - limited to tests required to determine if ARIS is good to go full 90 day mission (Green)
  - Setup & Crew Procedures Successful
  - Active Isolation Tests show isolation performance comparable to RME1313
- Minimum 30 day Mission Success Criteria (Blue)
  - Tests Required For Verification Completed
- Minimum Full Mission Success Criteria (Yellow)
  - Tests Required To Establish Performance Capability of ARIS For Future Users

Pre-Active Mode Procedures

BOEING

Setup & Functional Tests That Require The Crew	Objective
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]

Control Parameter Characterization Tests	Objective
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]

Environment & Active Functional Tests	Objective
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]

Acceleration Cancellation Tests

BOEING

Active Isolation Tests	Objective
[redacted]	[redacted]
[redacted] Required For Verification	[redacted]
[redacted] Required For Verification	[redacted]
[redacted] Required For Verification	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted] Required For Verification	[redacted]
[redacted] Required For Verification	[redacted]

Disturbance Tests	Objective
Crew push-off disturbance rejection and recovery test Required For Verification	Measure on-board acceleration and verify that the ARIS active acceleration control system recovers from a crew push-off within 5 seconds.
On-board disturbance rejection test	Apply calibrated force disturbance directly to payload and measure rejection capability. The ARIS actuators can be used to apply the disturbance.
Pump and Fan On/Off Test	Measure standard hardware disturbance impacts on on-board vibration
PCS Mix Mode Test	Measure PCS mix mode disturbance affect on on-board vibration.

Characterization & Performance Capability Tests

BOEING

Standby Tests	Objective
Passive Isolation Test	Determine transmission affects from umbilicals and other disturbance sources independent of active control actuator commands.
Small Amplitude Variation Stiffness Test	Measure full umbilical small amplitude stiffness at off-center locations.
Control Parameter Characterization & Selection	**Objective**
Decoupling Test	Determine to what extent the isolation performance can be improved at the accelerometer heads by selecting appropriate off-diagonal stiffness cancellation control parameters.
Low Frequency High Gain Test	Determine sway space limit on acceleration gain due to measurement noise
Stiffness Cancellation Test	Determine to what extent the isolation performance can be improved overall by selecting appropriate diagonal stiffness cancellation control parameters.
High Frequency Gain Margin Test	Determine the gain margin and maximum achievable bandwidth by turning up the acceleration loop gain. Determine to what extent the isolation performance can be improved near cross over by selecting appropriate stabilization filter control parameters.
Anti-Bump Test	Determine isolation performance with anti-bump activated
Transition or Secured Rack Acceleration Tests	**Objective**
Active-to-Soft Standby & Soft Standby-to-Active Transition Response Test Required For Verification	Measure acceleration transient
Bumper Lockdown Hold Test Required For Verification	Measure rack accelerations while in the secured state.
Active Mode Characterization Tests	**Objective**
Accelerometer Temperature Compensation Test	Sway Space Sensitivity Acceleration Measurement Drift Due To Temperature
Simulated Isolation Test (ARIS commanded)	Measure closed loop response to acceleration commands. Coupling affects are measured directly and low frequency isolation can be extracted from data.
Accelerometer Redundancy Test	Measure performance impacts if 7 accelerometers are used instead of 8.

ICE Data Interface Configurations

BOEING

- ARIS Standard Configuration (SC)
  - ARIS/EXPRESS rack is in nominal ARIS/EXPRESS configuration.
  - Communication with ARIS Controller is through the EXPRESS RIC.
- ICE-Unique or POP Configuration (PC)
  - ICE-Unique 1553 cable is connected between POP and ARIS Controller.
  - Communication with ARIS Controller is through the ICE POP.

Generic Test Sequences

BOEING

- Standard Configuration, Reduced Sway Space Testing
- ICE-Unique Configuration, Reduced Sway Space Testing
- ICE-Unique Configuration, Full Sway Space Testing
- ARIS Standard Configuration, Full Sway Space Testing
- ICE-Unique Configuration, Full Sway Space, Commanded Response Testing
- ICE-Unique Configuration, Full Sway Space, Degraded Mode Testing
- ICE-Unique Configuration, Full Sway Space, Automatic Response Testing
- ICE-Unique Configuration, Full Sway Space, Long-Term Microgravity Mode Testing
- ICE-Unique Configuration, Full Sway Space, Payload Variation Testing

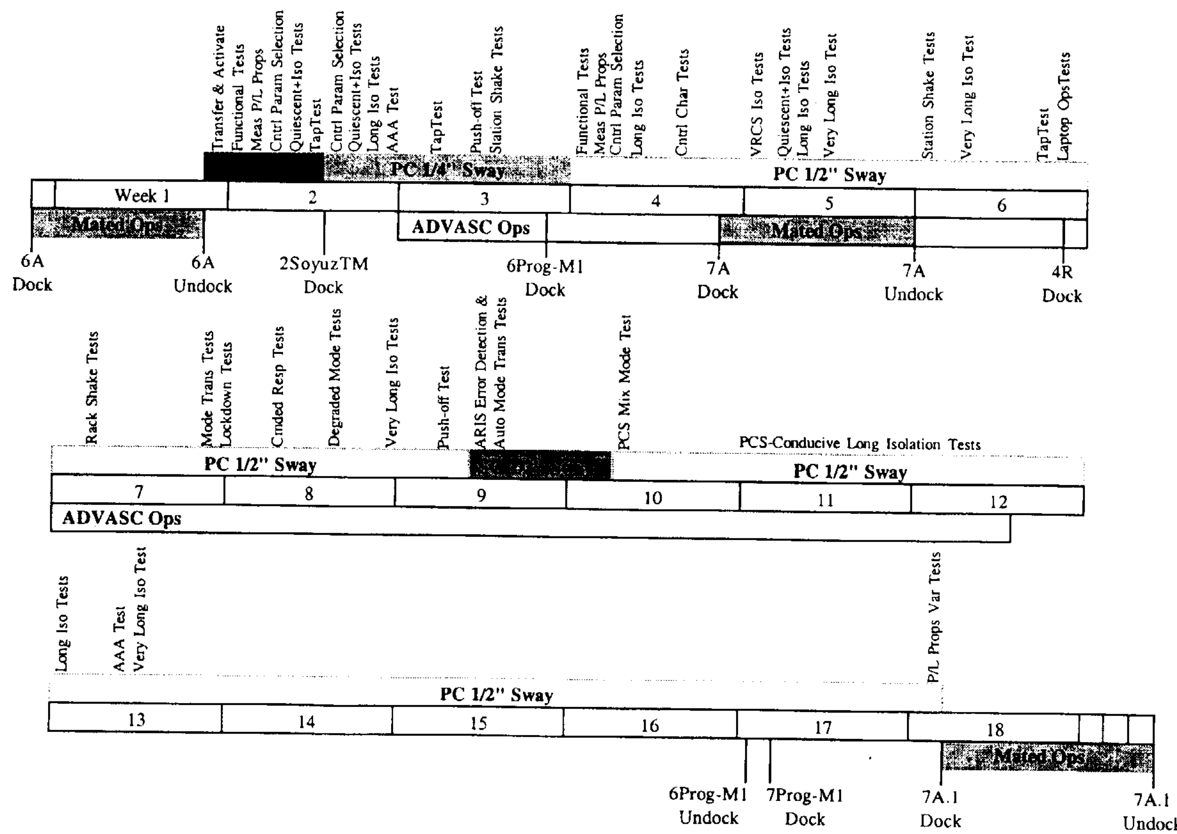
ICE Operations Overview

BOEING

- ICE Pop and Shaker manifested on Flight 6A
  - EXPRESS #2 ascent in MPLM
  - ARIS pre-integrated in EXPRESS #2
  - POP flies in EXPRESS #2 single locker
  - Most shaker components stowed in EXPRESS #2 locker
  - Other hardware stowed in unspecified stowage location (probably Resupply Stowage Platform)
- ICE conducted during Increment 2
  - Nominal 90 day experiment
- Crew ops include set-up, reconfiguration, shaker activation
- Ground control is primary experiment operation mode
- Pop and Shaker return on 7A.1 after transfer to unspecified descent stowage locations

ARIS-ICE Timeline

BOEING



08/31/99

520/29

2000/7 /0 512587 56PS

Paper Number: 20

Microgravity Vibration Isolation Mount (MIM) update and CSA plans for isolation systems on the ISS

Bjarni V. Tryggvason
Canadian Space Agency
St. Hubert, Quebec, Canada

Over the past eight years or so the Canadian Space Agency (CSA) has developed and flown in space the Microgravity Vibration Isolation Mount (MIM). The first version, MIM-1, flew on the Mir space station and was operated for over 3000 hours in support of several material science and fluid science experiments. The second version, MIM-2, flew on shuttle mission STS-85. This work has demonstrated both the need for isolation systems on the International Space Station (ISS) and the success of the approach used for the MIM. Over the past two years the work has shifted to addressing CSA science needs on the ISS. Two quite different systems based on the MIM technology are planned for the ISS with launches expected in 2003. One system, the Microgravity Vibration Isolation Subsystem (MVIS), has been developed in collaboration with the European Space Agency and will be installed into the ESA Fluid Science Laboratory. The second system, the MIM Base Unit (MIMBU), will be installed into an EXPRESS rack and will be designed to support numerous material science and fluid science experiments. These systems and their expected performance will be described in the presentation.

Microgravity Vibration Isolation Mount (MIM) Update and CSA Plans for Isolation Systems on the ISS

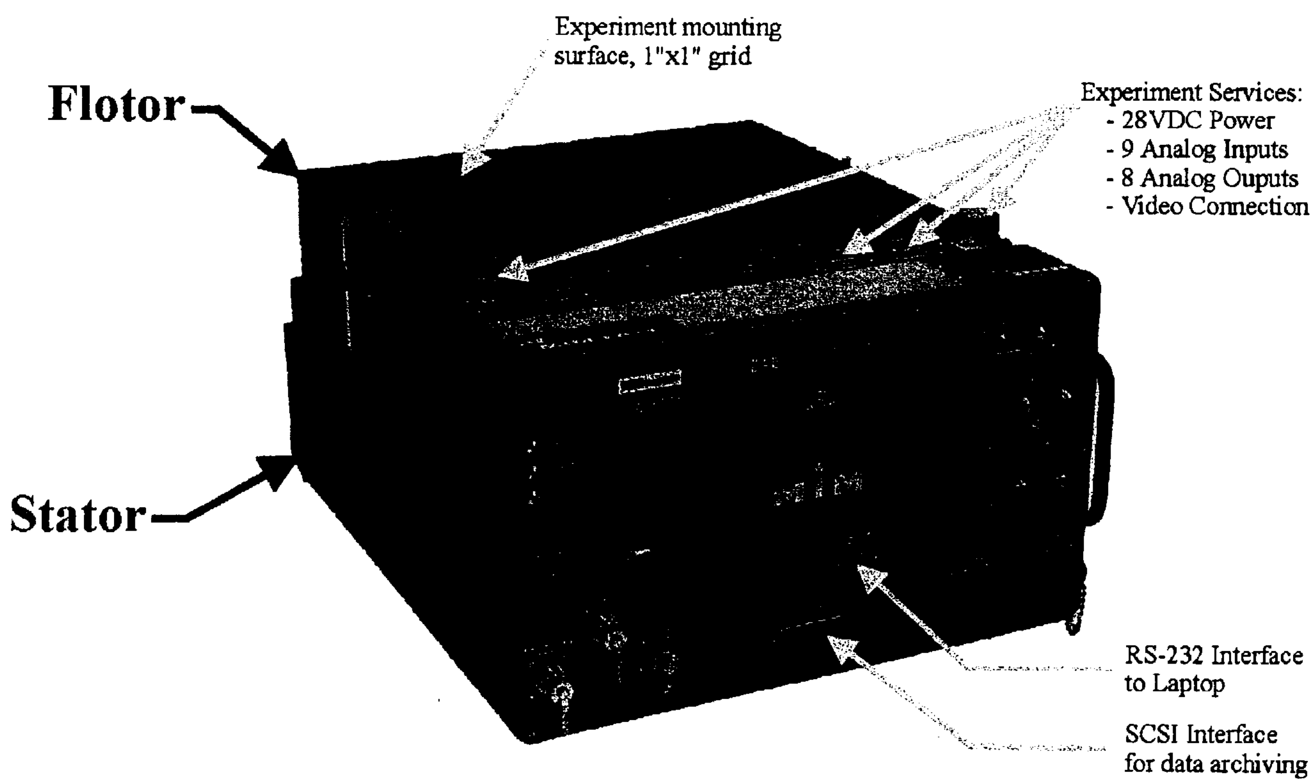
Bjarni V. Tryggvason
Canadian Space Agency

MGMG 19 July 11, 2000

Outline

- MIM Acceleration Measurements on Mir
  - High Frequency
  - Low Frequency
- MIM Acceleration Measurements on the Shuttle
- MIM Performance
- CSA Plans for Isolation Systems for the ISS
  - MIM Base Unit (MIMBU)
  - Microgravity Vibration Isolation Subsystem (MVIS) for the ESA Fluid Science Laboratory (FSL)

MIM-2



Experiment mounting
surface, 1"x1" grid
Flotor
Experiment Services:
- 28VDC Power
- 9 Analog Inputs
- 8 Analog Ouputs
- Video Connection
Stator
RS-232 Interface
to Laptop
SCSI Interface
for data archiving

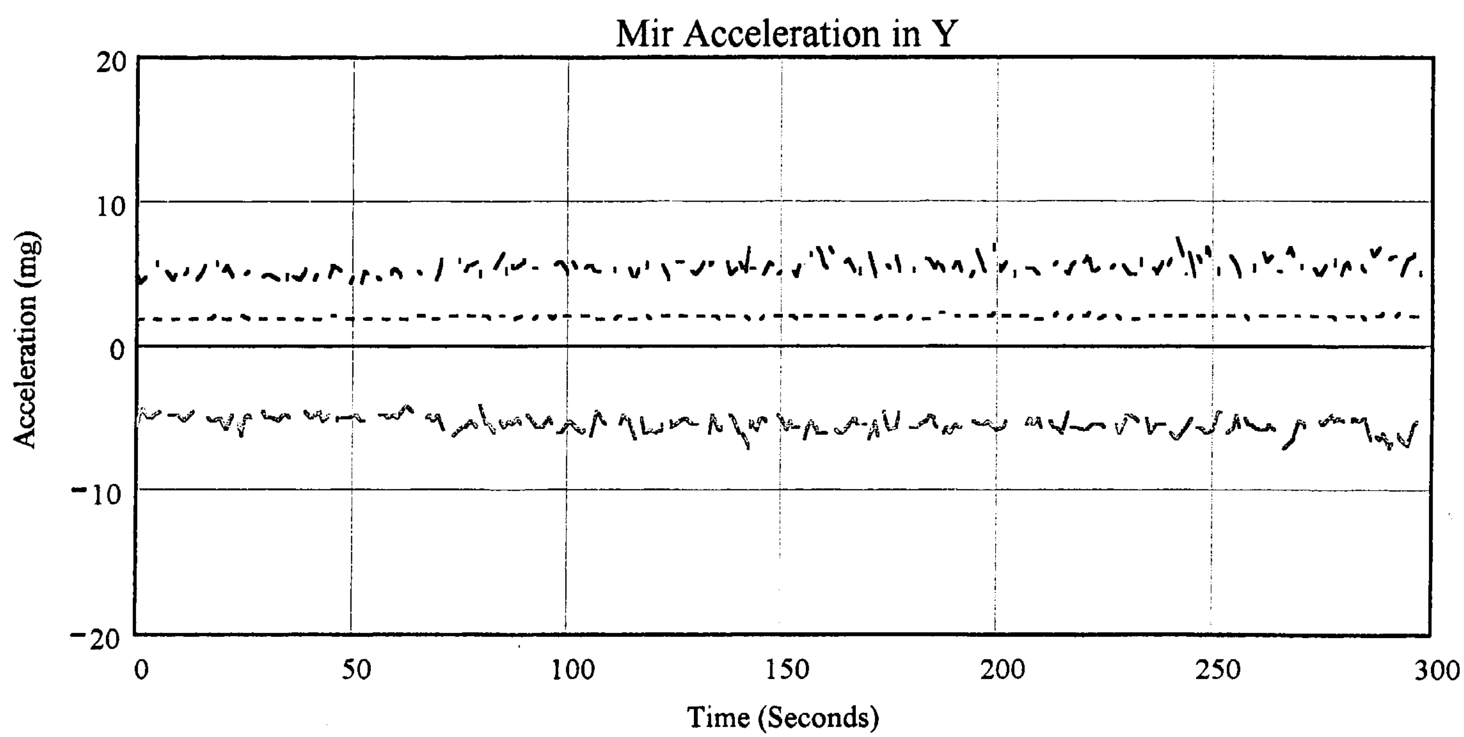
MIM-1 Operations on Mir

- Operational from May 1996 to January 1998
  - 3000 hours of operations supporting material science experiments:
    - Diffusion in liquid metals
    - Nucleation in glasses
    - Particle pushing
    - Semiconductor crystal growth
    - Protein crystal growth
    - Liquid-vapor interface dynamics
  - Processed more than 200 samples

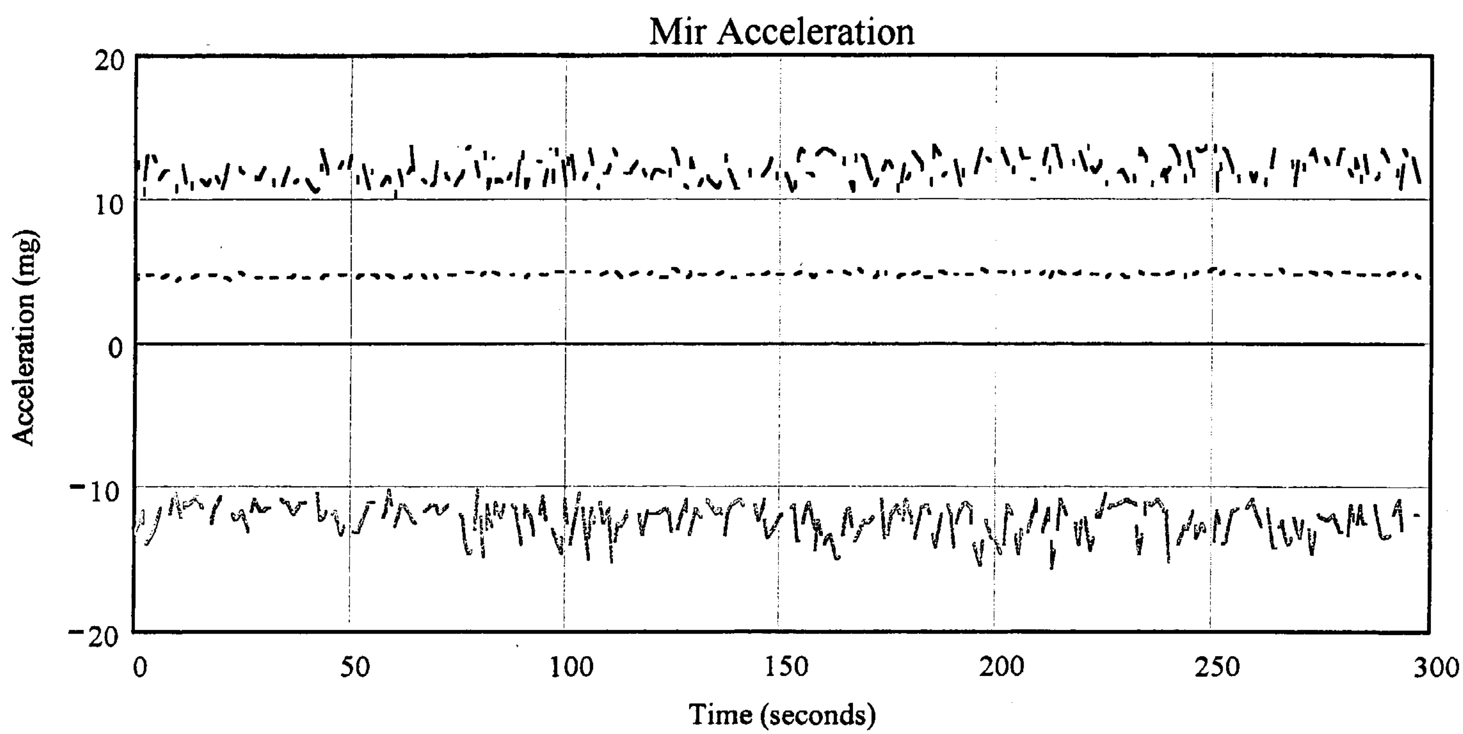
Format for Presentation of Time Histories for Accelerations

- On the time traces four lines are plotted on each figure. These are the following statistics:
  - Maximum acceleration sampled over a one second interval
  - Minimum acceleration sampled over a one second interval
  - Standard deviation of the acceleration over the one second interval
  - The mean acceleration over the one second interval, with the mean for the whole record removed

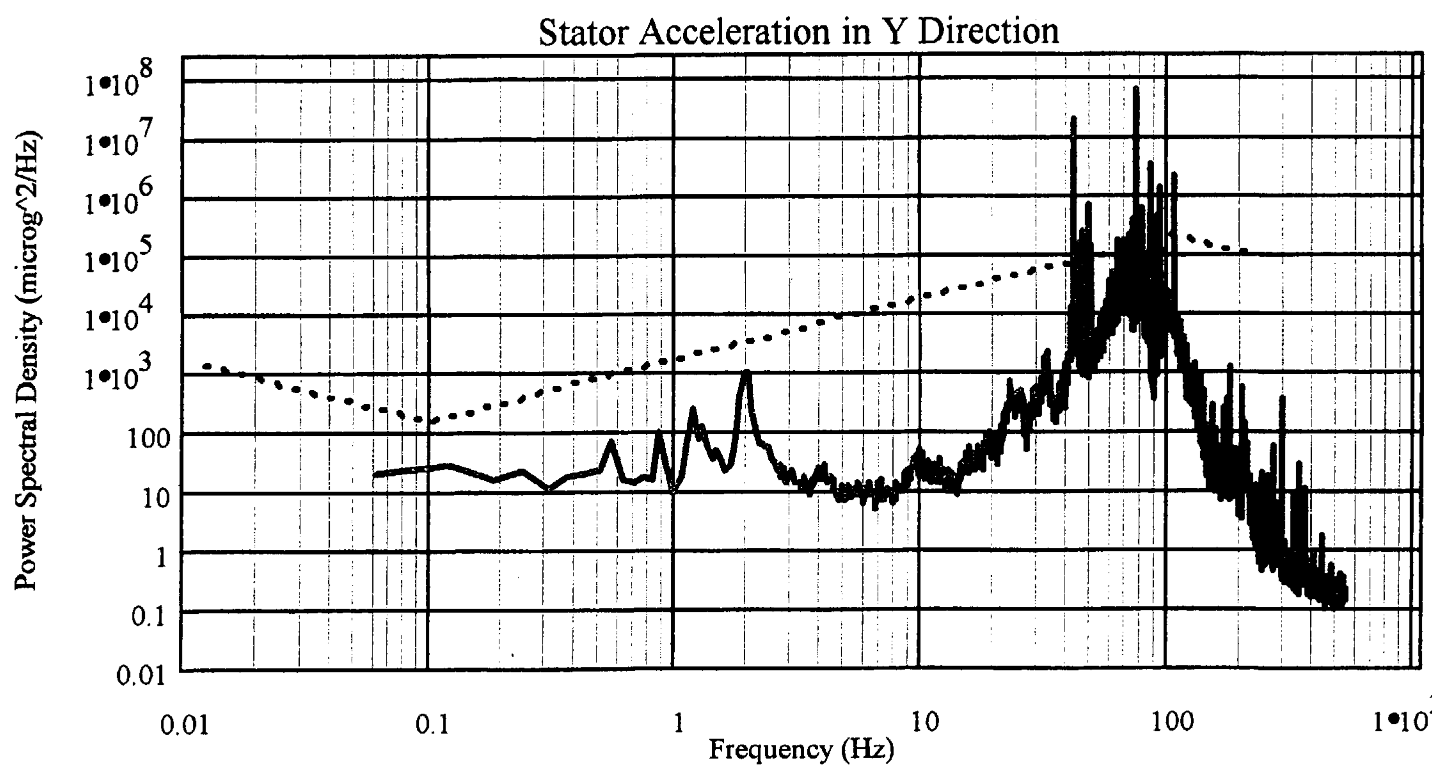
Accelerations on Mir as Measured with the MIM



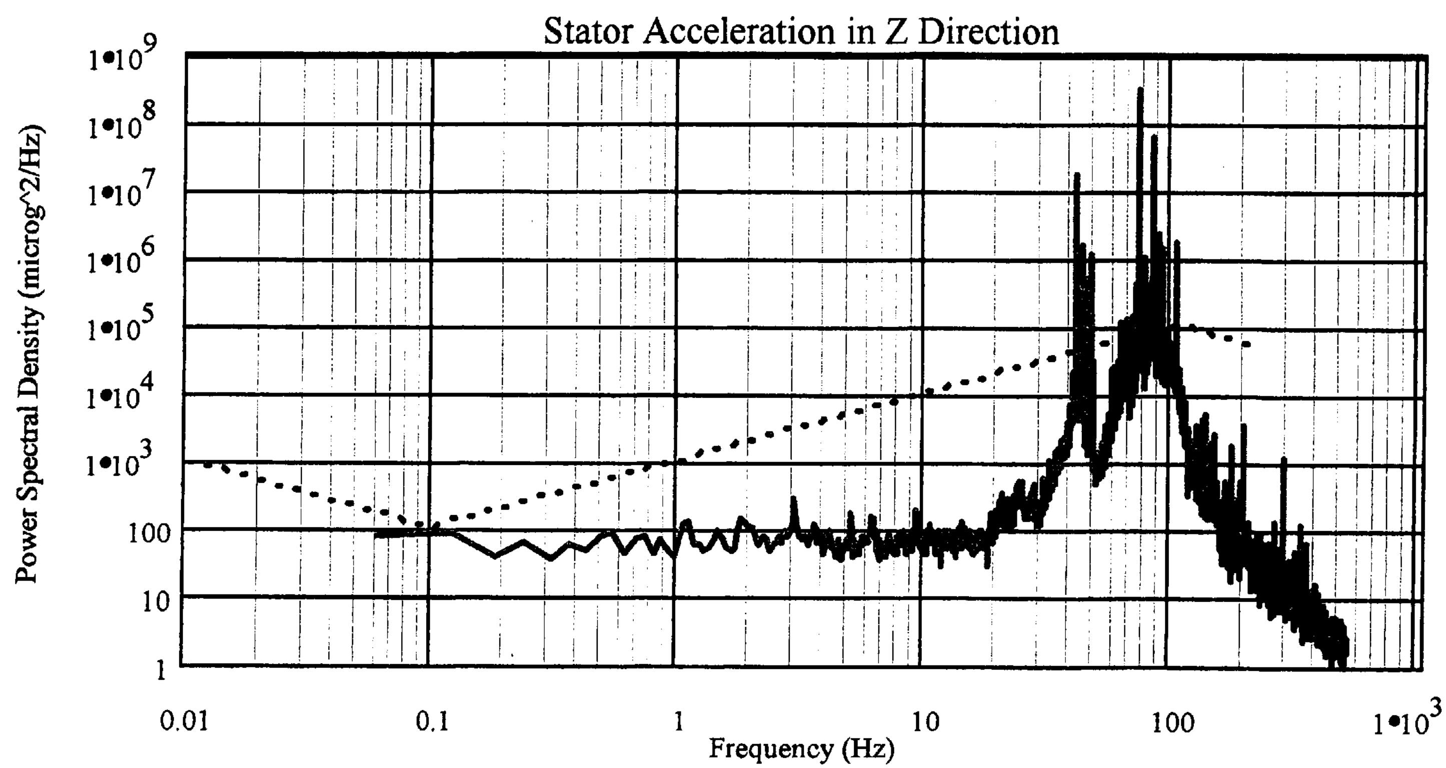
Accelerations on Mir as Measured with the MIM



Accelerations on Mir as Measured with the MIM

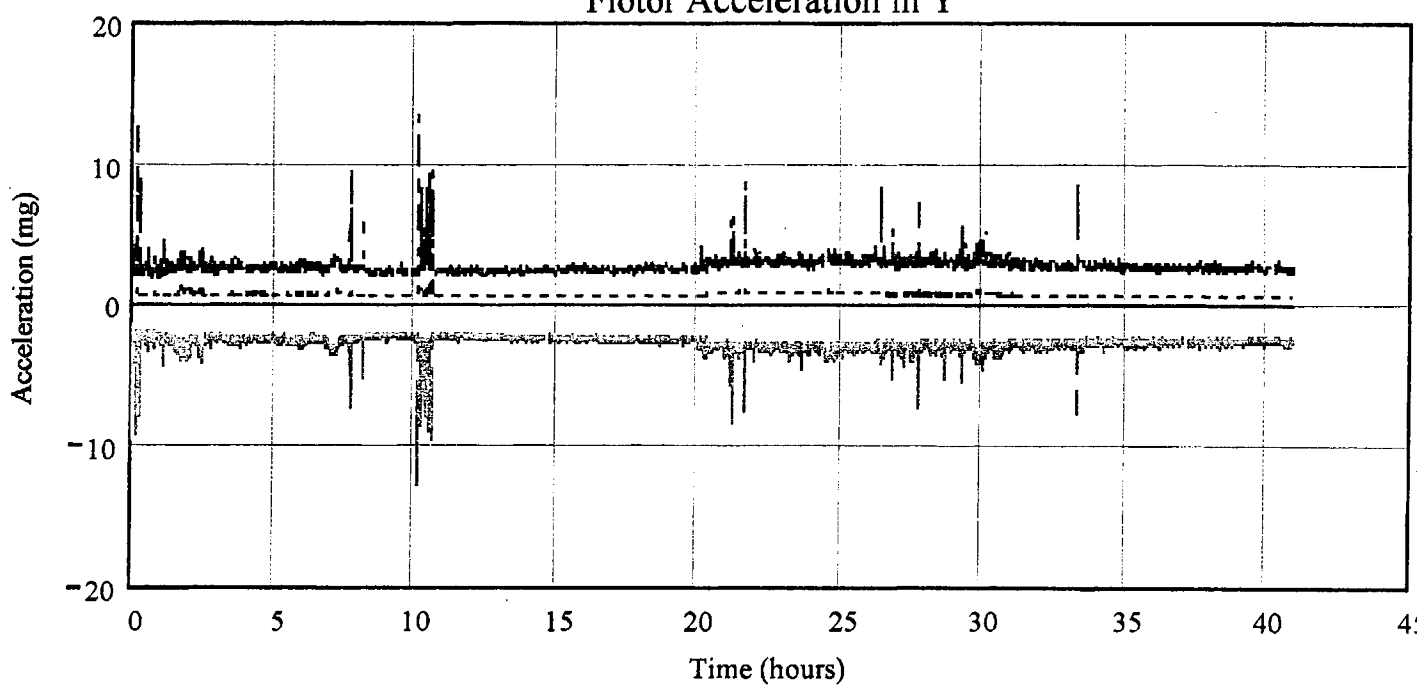


Accelerations on Mir as Measured with the MIM



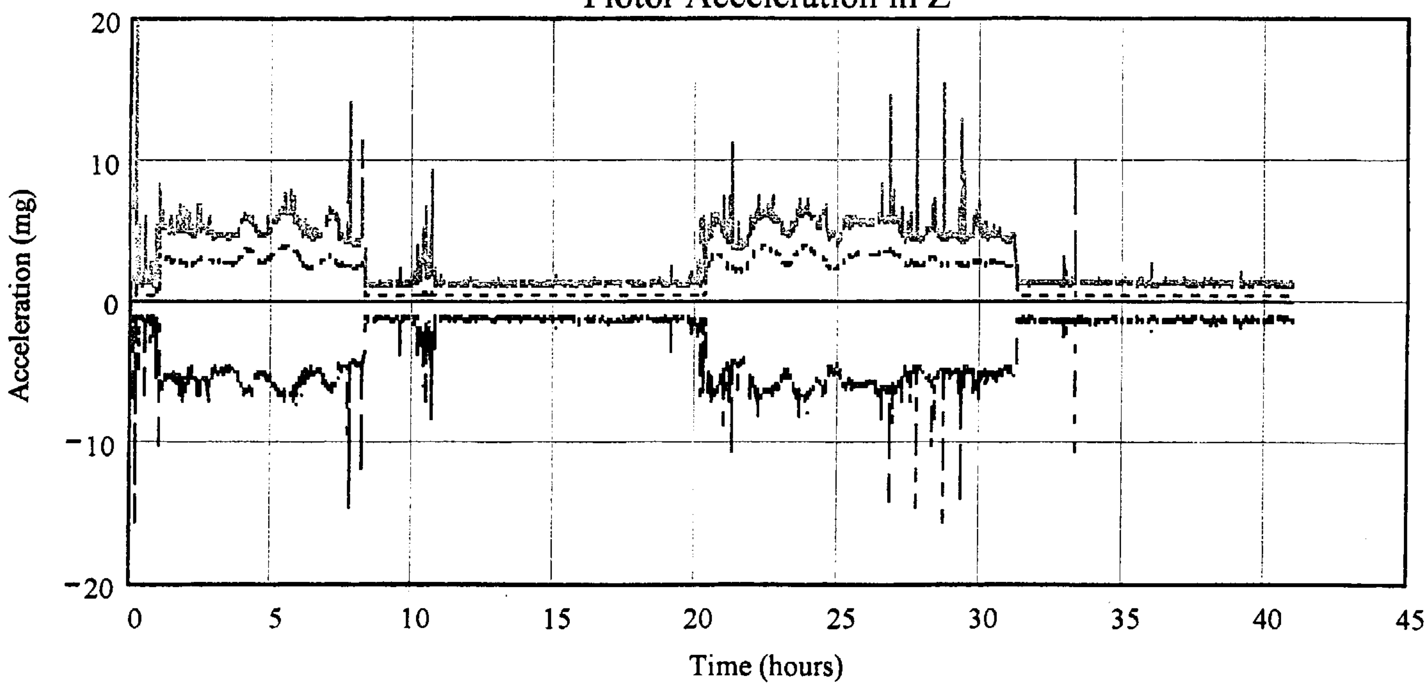
Accelerations on Mir as Measured with the MIM

Flotor Acceleration in Y

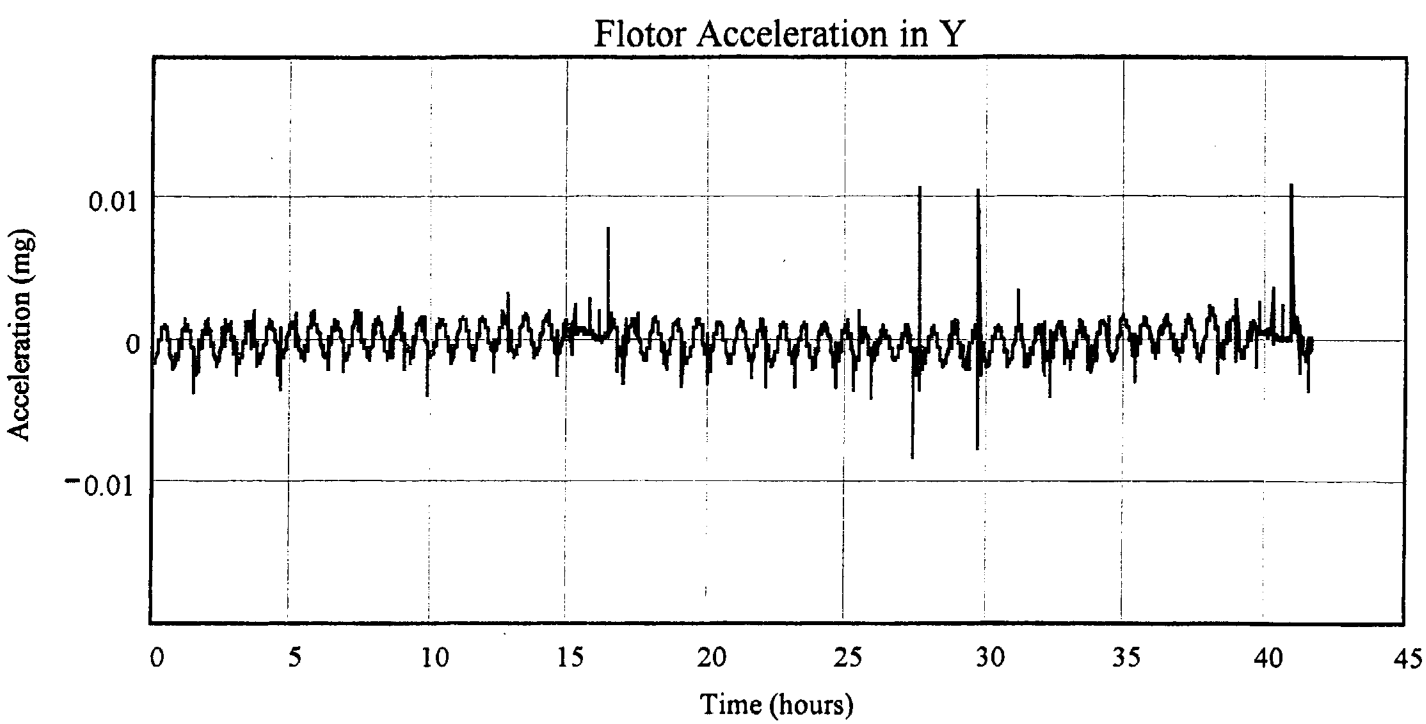


Accelerations on Mir as Measured with the MIM

Flotor Acceleration in Z

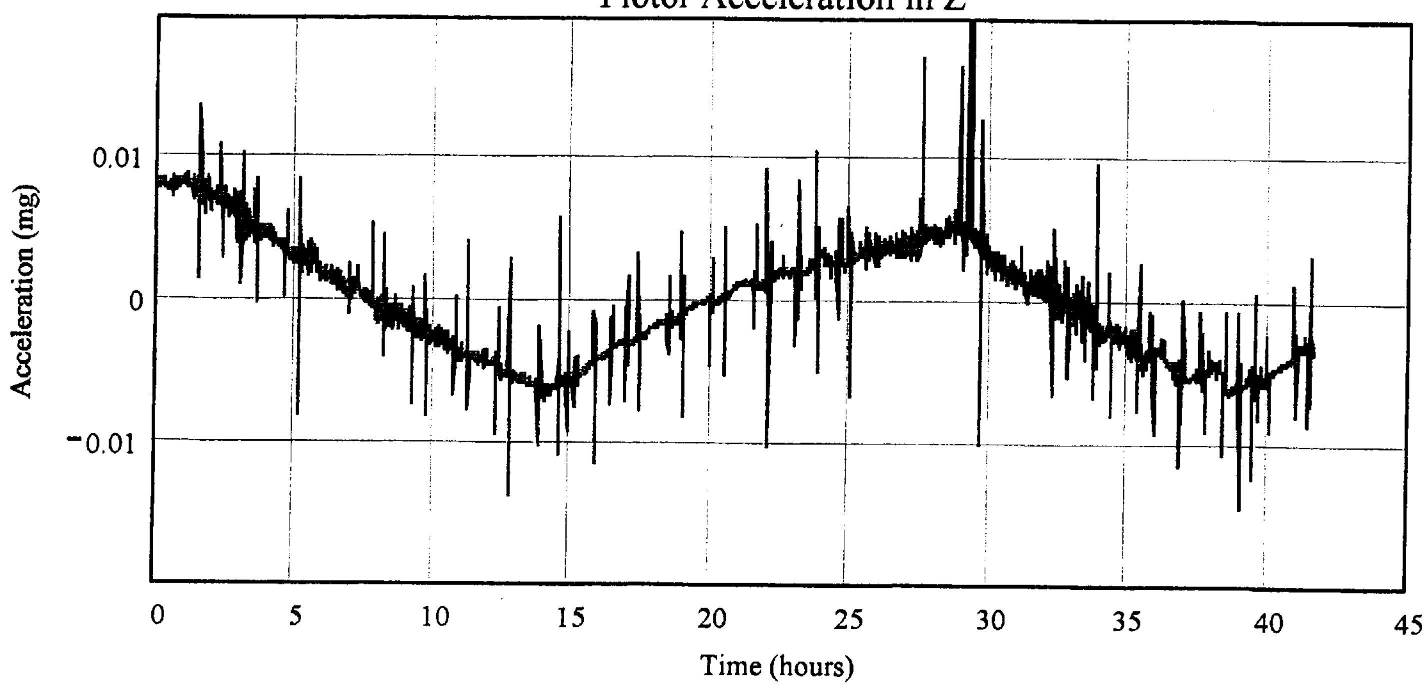


Mean Acceleration on and Expanded Scale

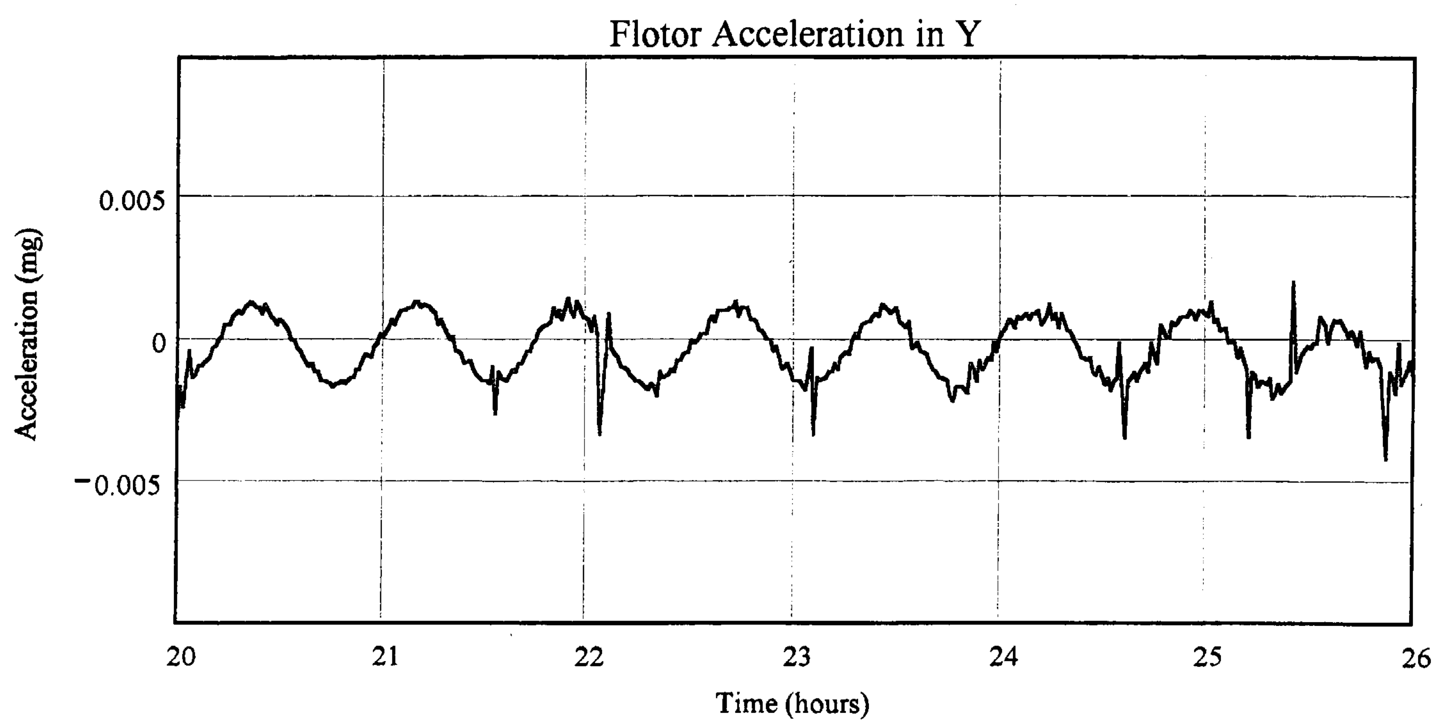


Mean Acceleration on and Expanded Scale

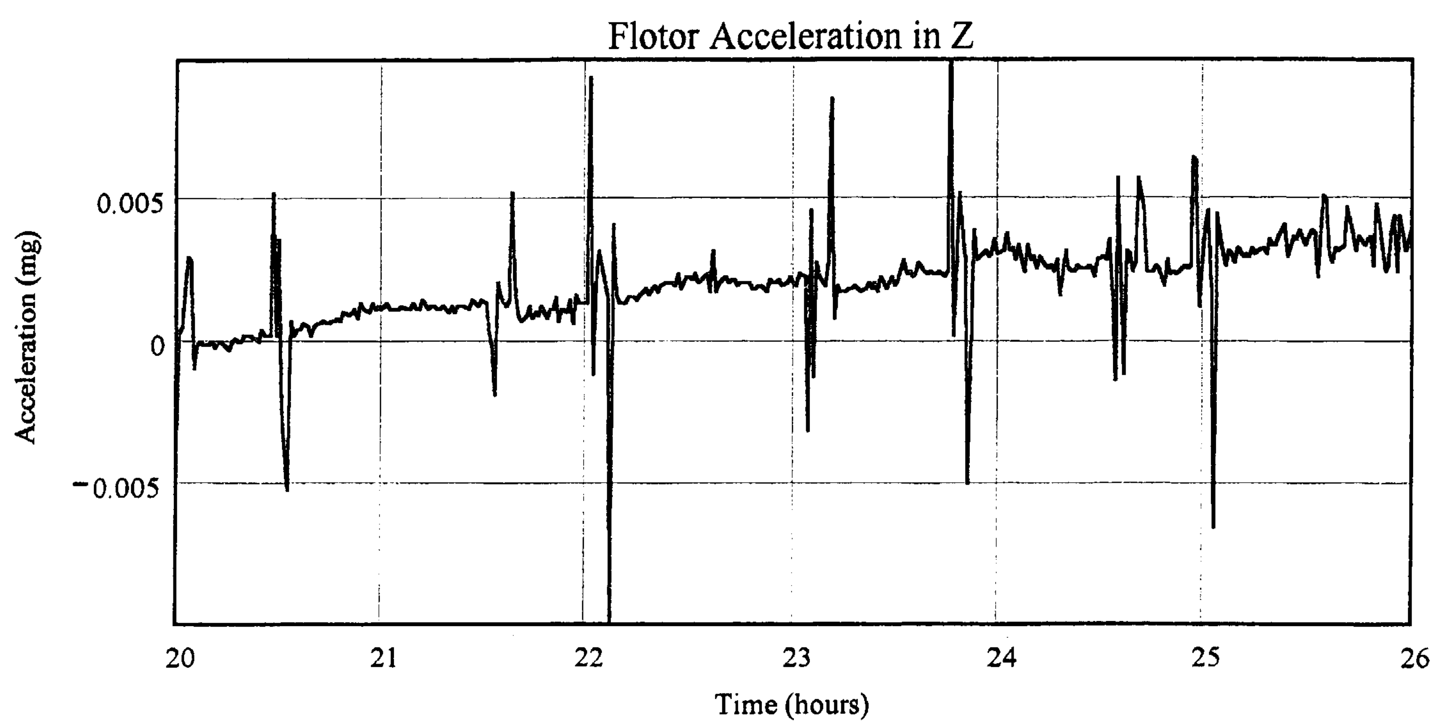
Flotor Acceleration in Z



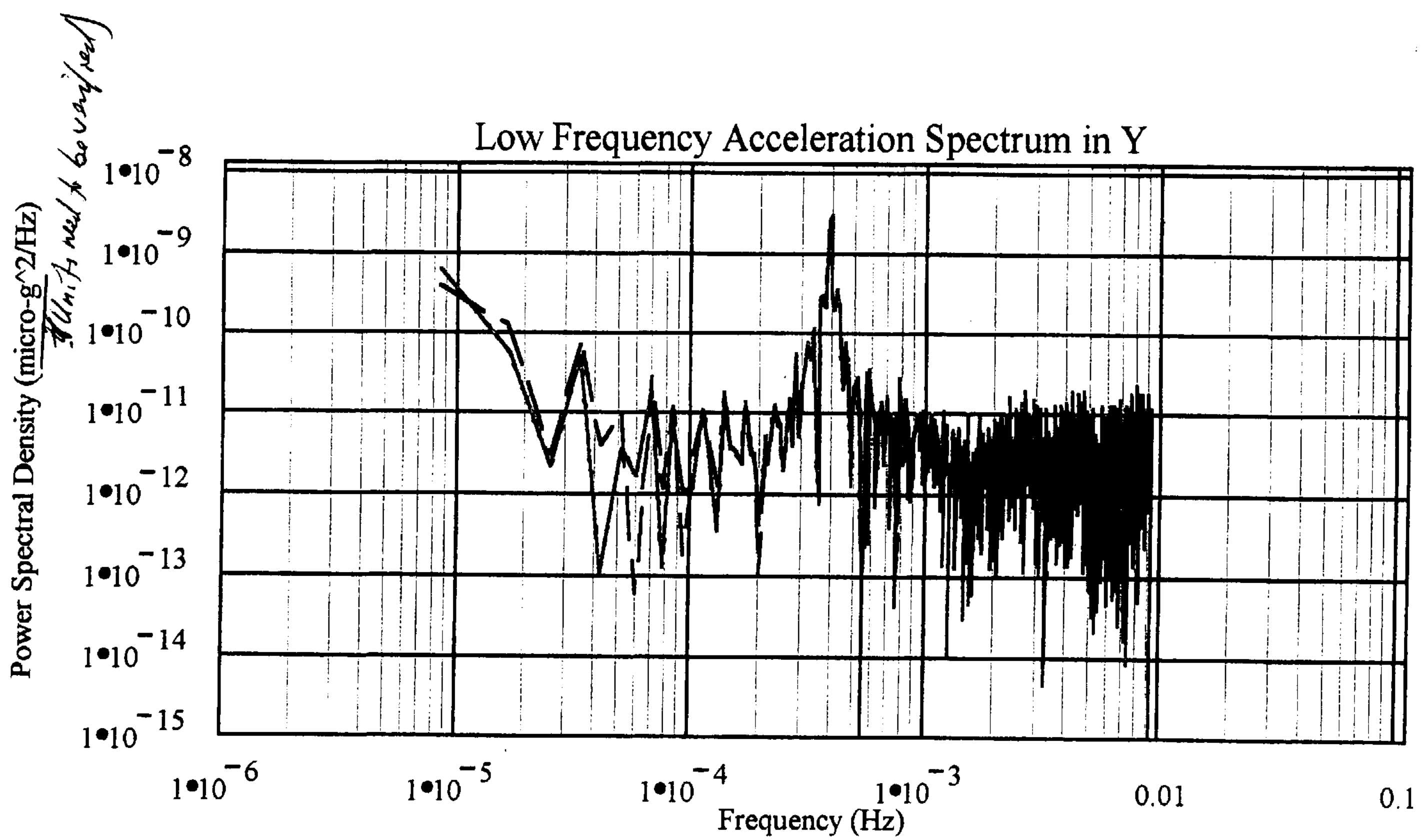
Mean Acceleration on and Expanded Scale



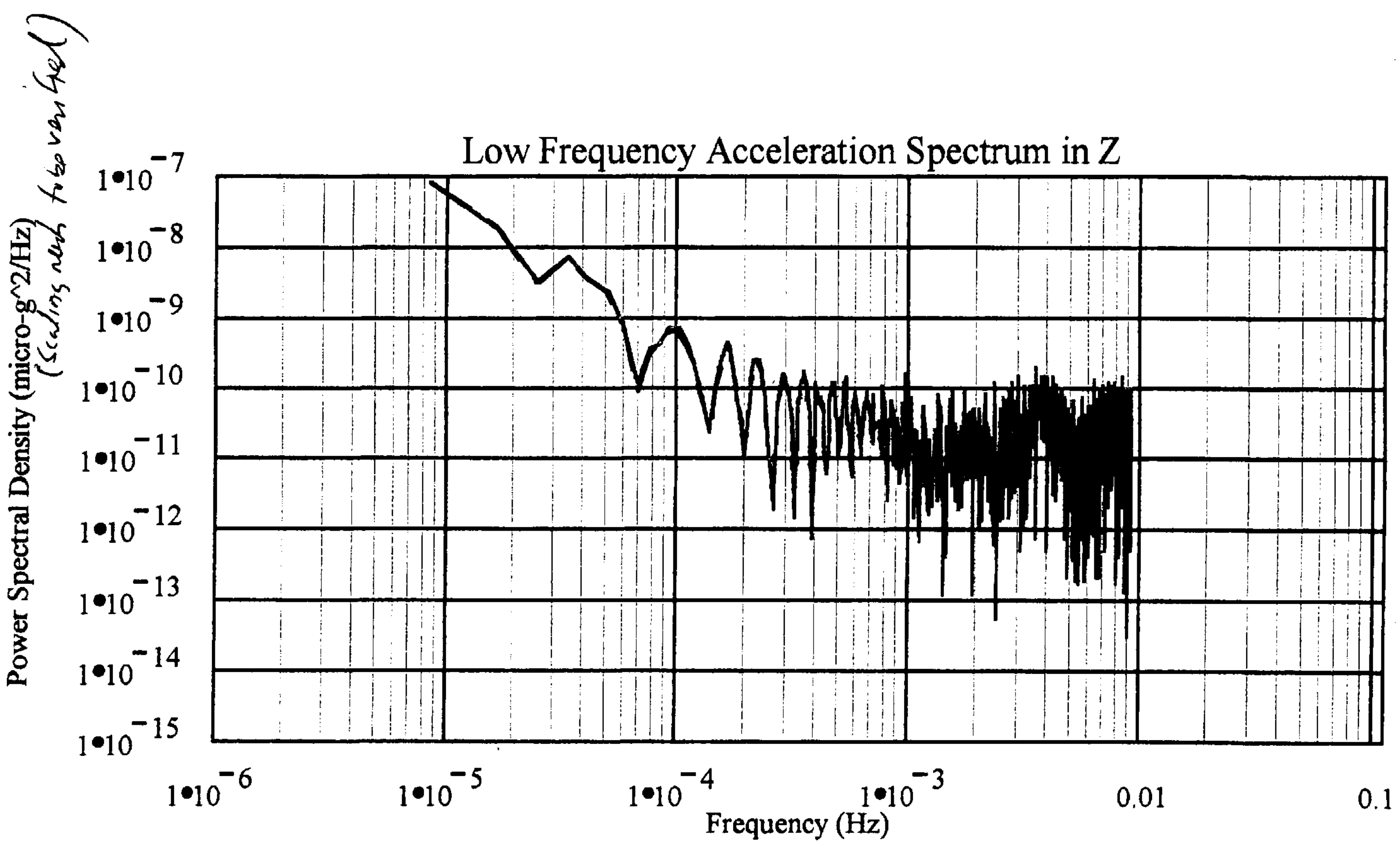
Mean Acceleration on and Expanded Scale



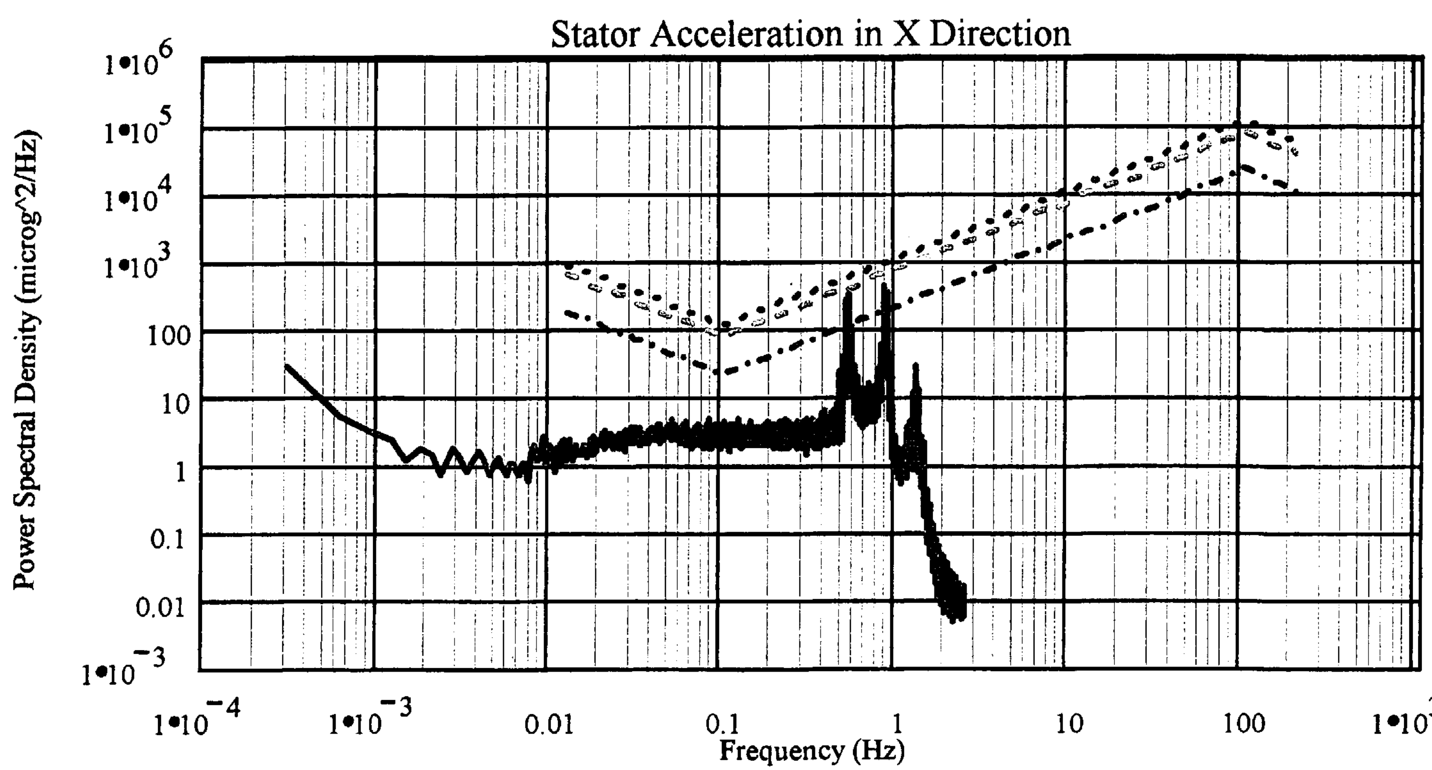
Spectrum for Low Frequency Acceleration on Mir



Spectrum for Low Frequency Acceleration on Mir



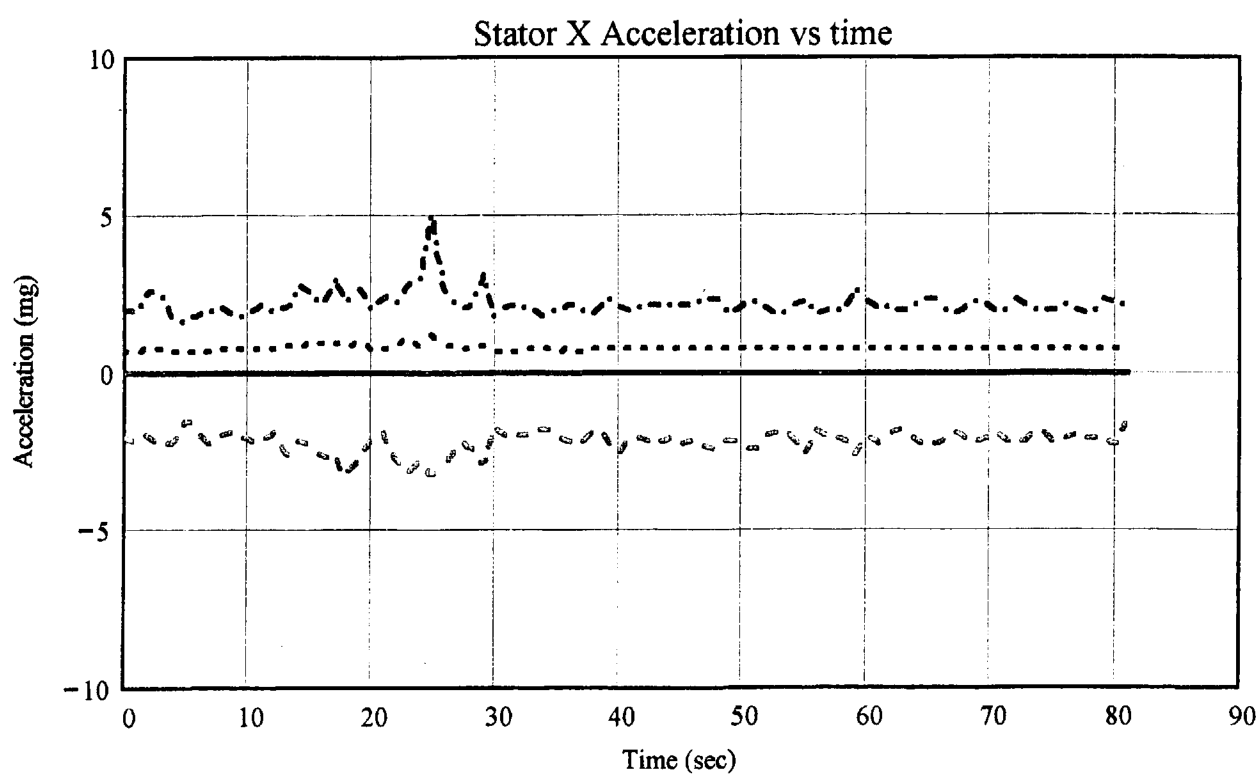
Spectrum for Intermediate Frequency Acceleration on Mir



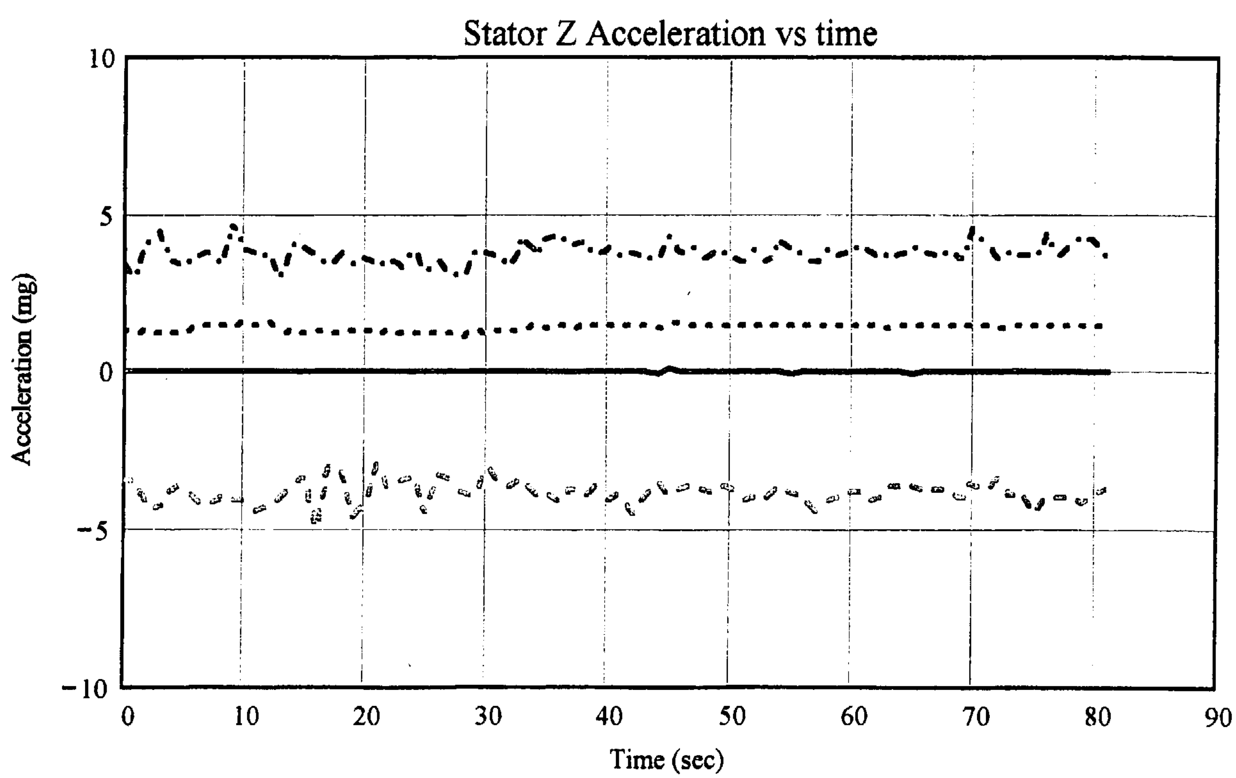
MIM-1 Operations on STS-85

- August 7-19, 1997
  - Operated 50 hours to look at MIM performance
    - Isolation performance
    - Driven mode performance
      - Random broad band
      - Sinusoidal, single and multiple frequencies
  - Operated 50 hours in support of fluid science experiments designed to examine g-jitter effects:
    - Brownian Motion
    - Liquid-liquid interface dynamics
    - Liquid-vapor interface dynamics
    - Motion of encapsulated bubbles

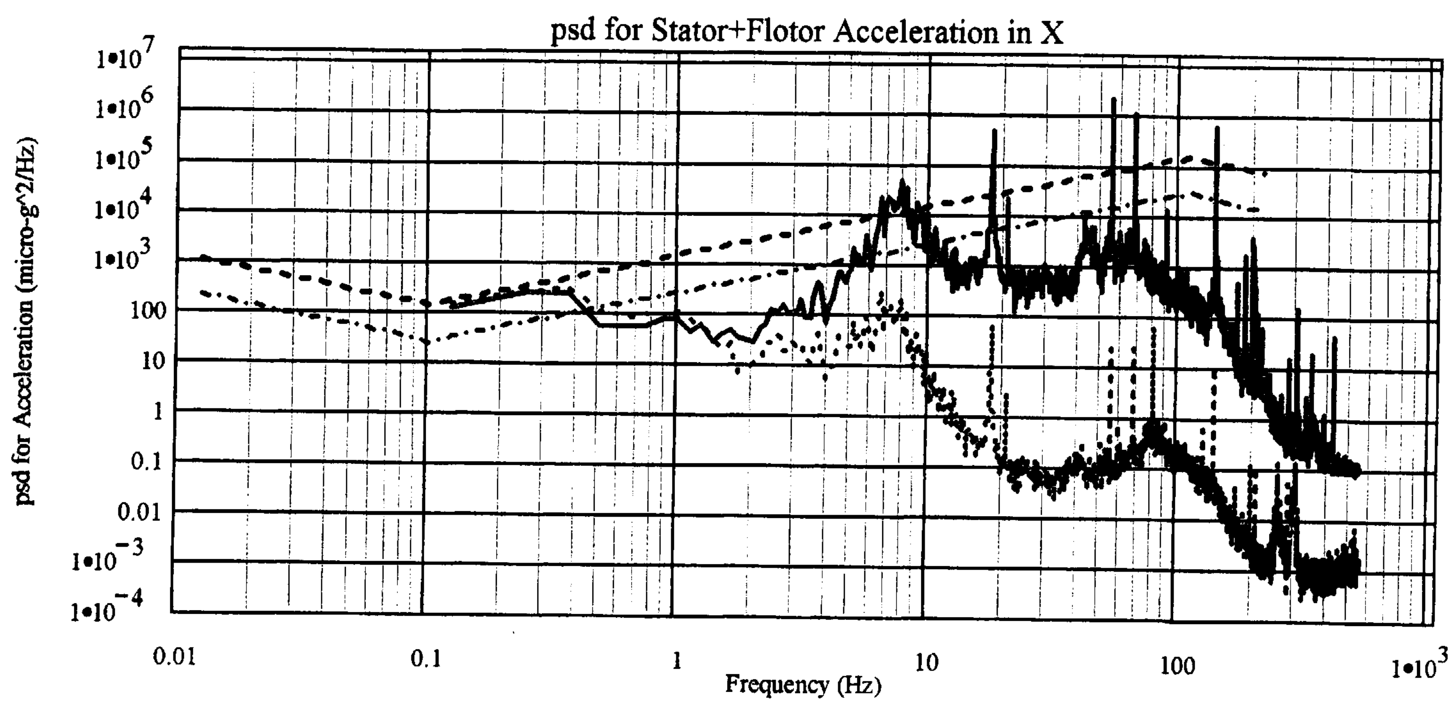
Acceleration on the Shuttle



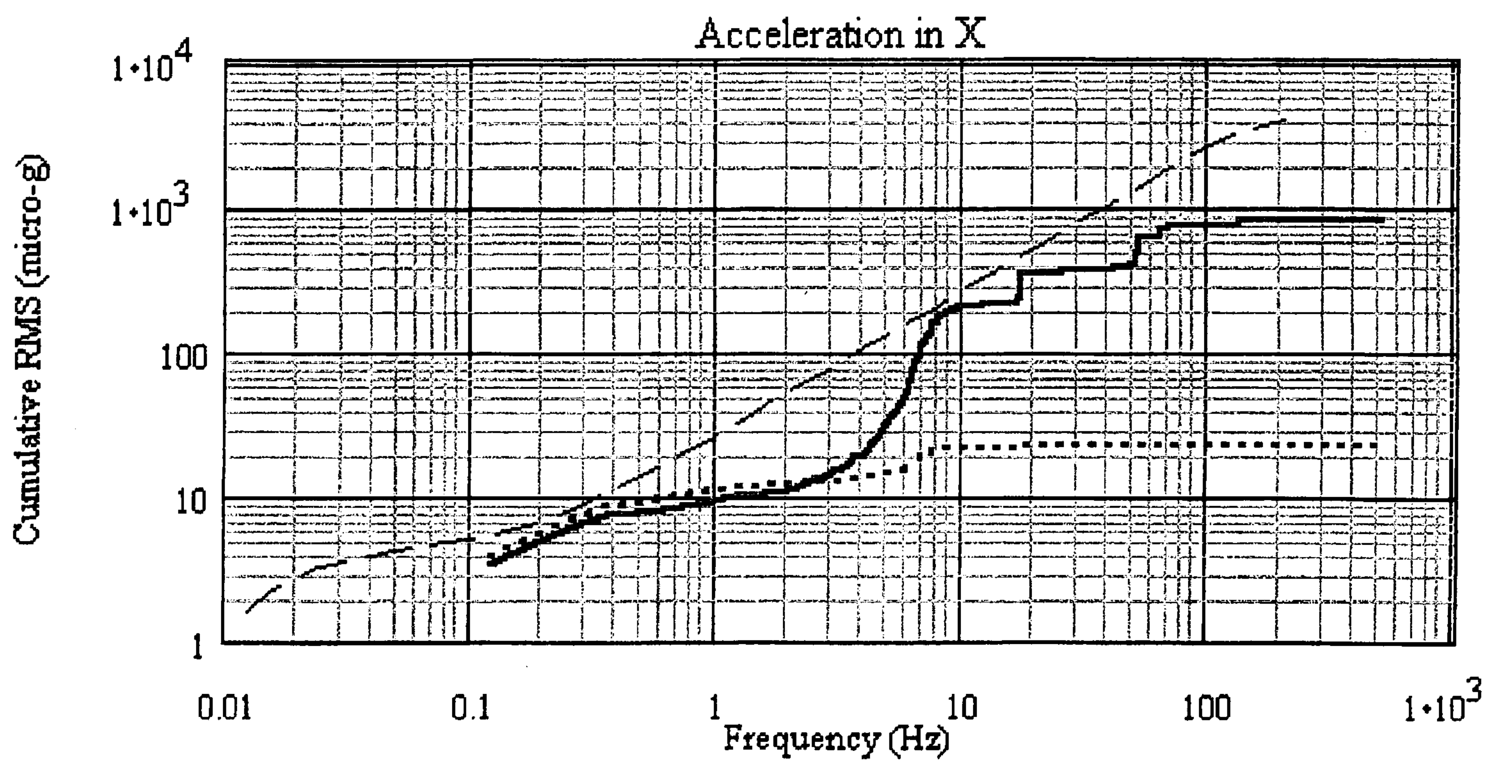
Acceleration on the Shuttle



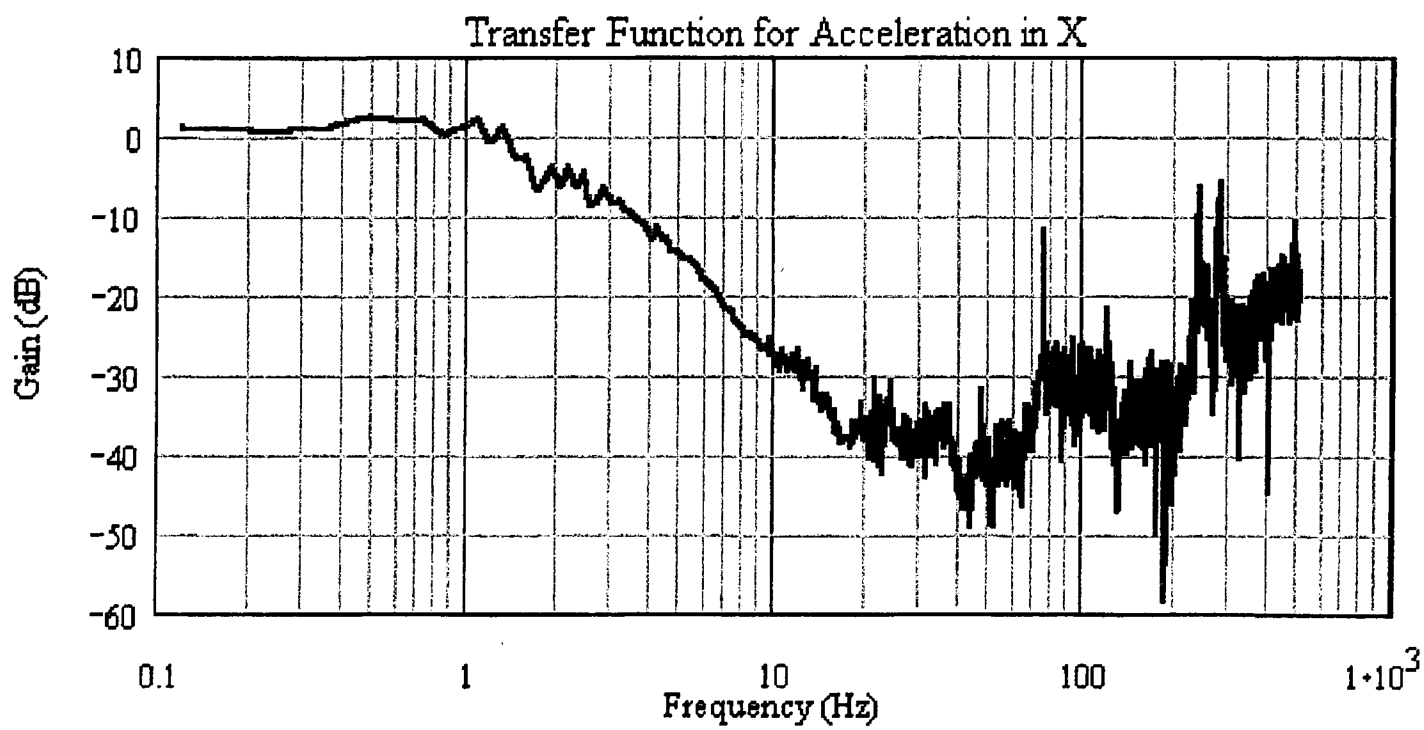
Acceleration on the Shuttle
Run 7080820: 2.0 Hz Cutoff Frequency



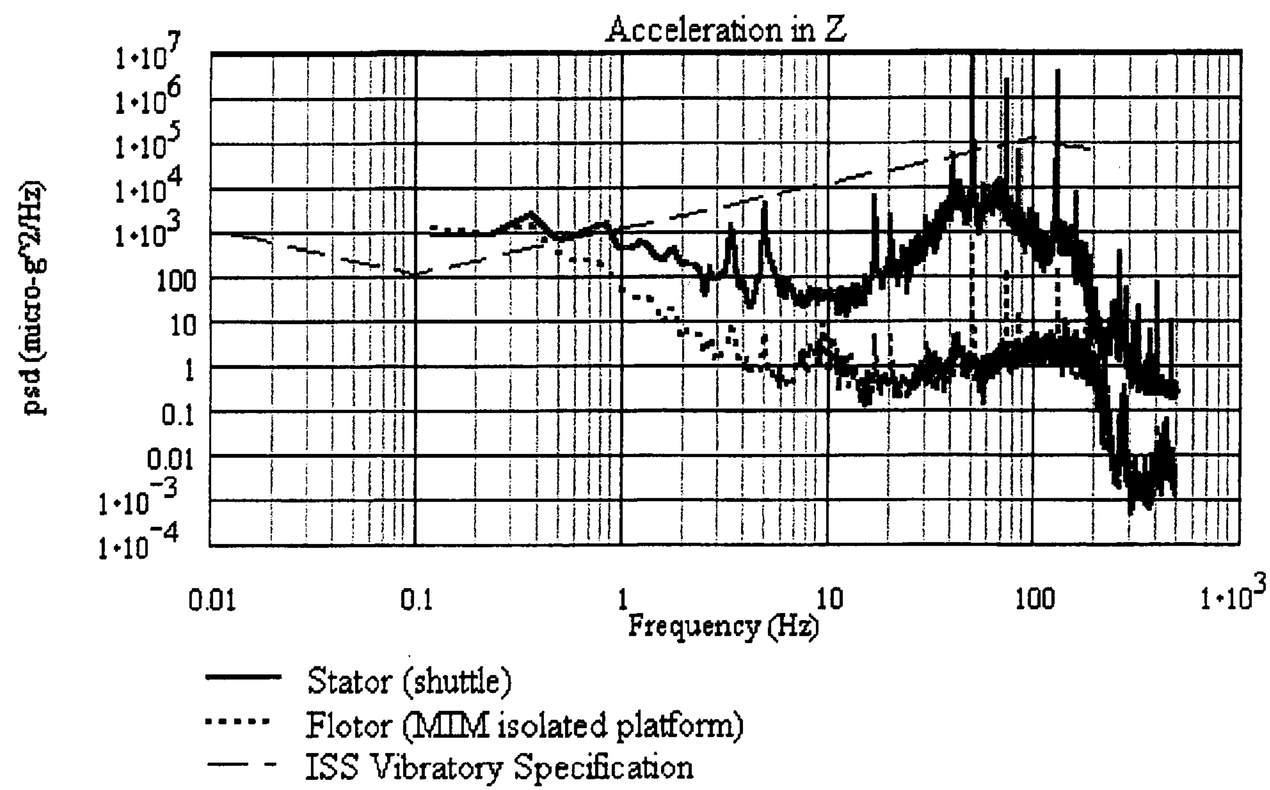
Accelerations on the Shuttle
Run 7080820: 2.0 Hz Cutoff Frequency



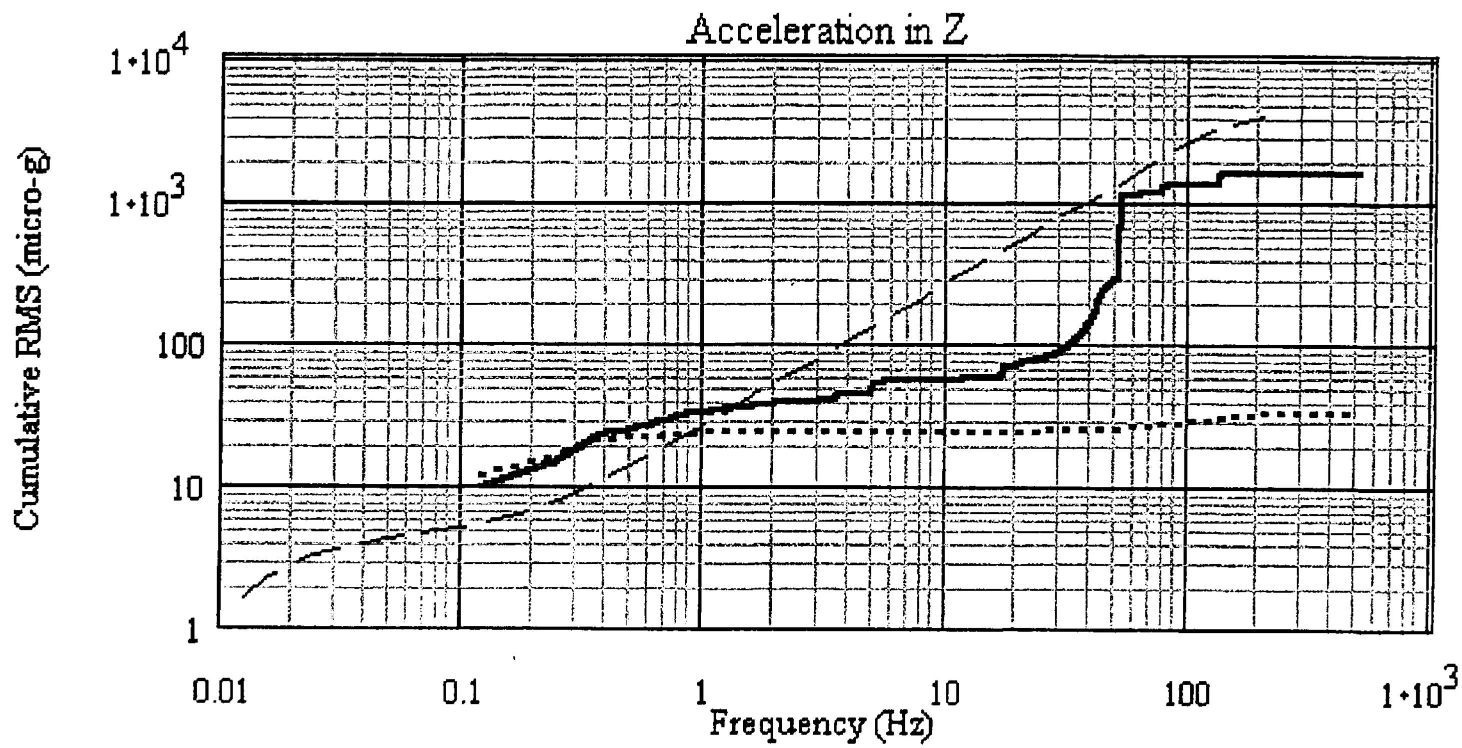
MIM-2 Isolation Transfer Function
Run 7080820: 2.0 Hz Cutoff Frequency



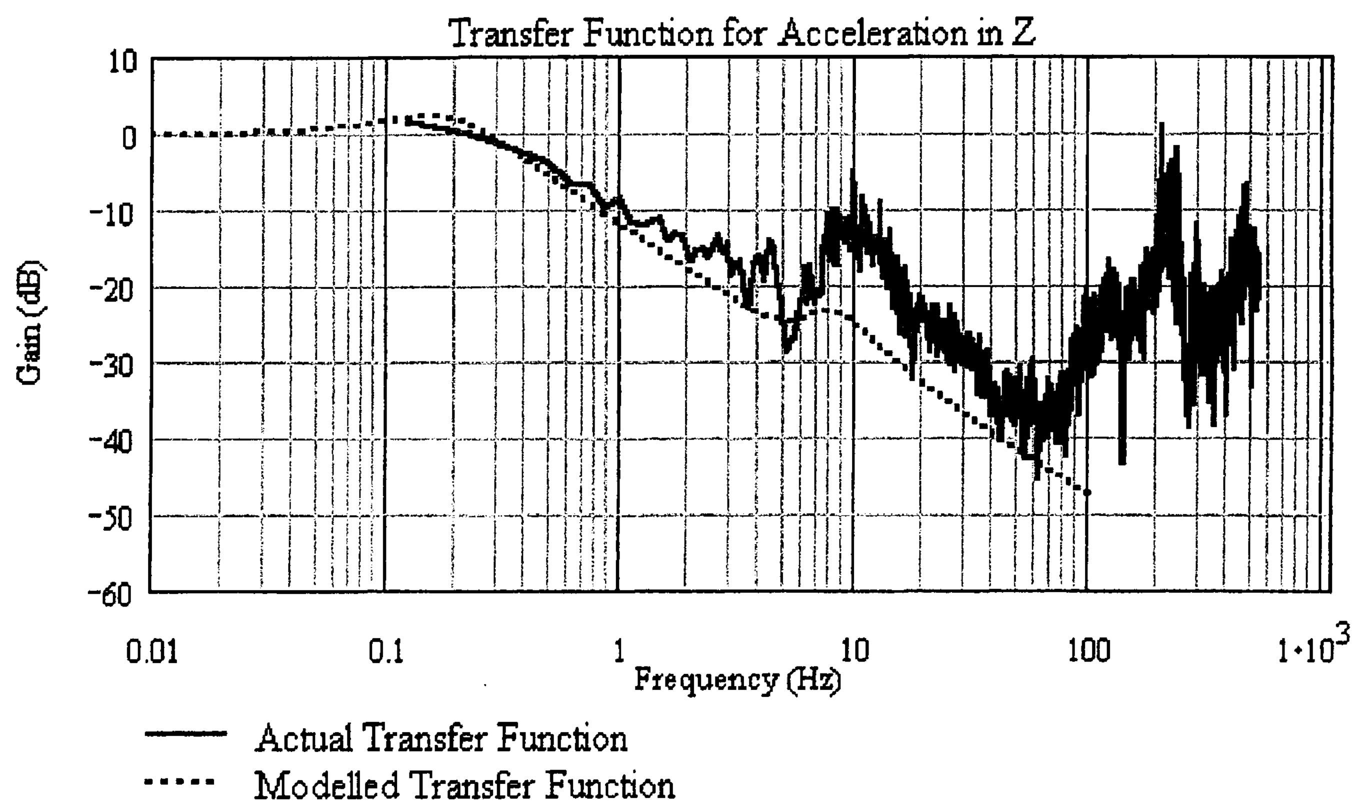
Acceleration on the Shuttle
Run 708162:1 0.3 Hz Cutoff Frequency



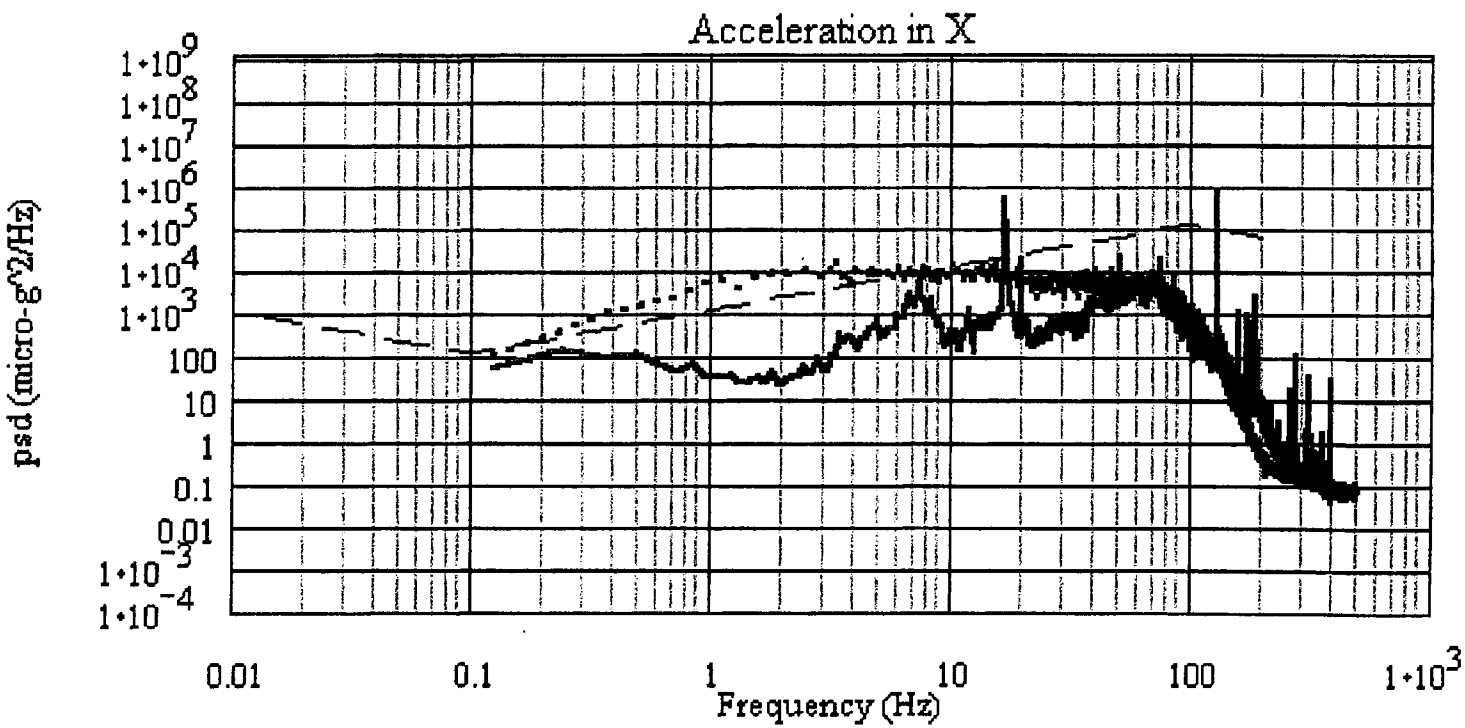
Acceleration on the Shuttle
Run 708162:1 0.3 Hz Cutoff Frequency



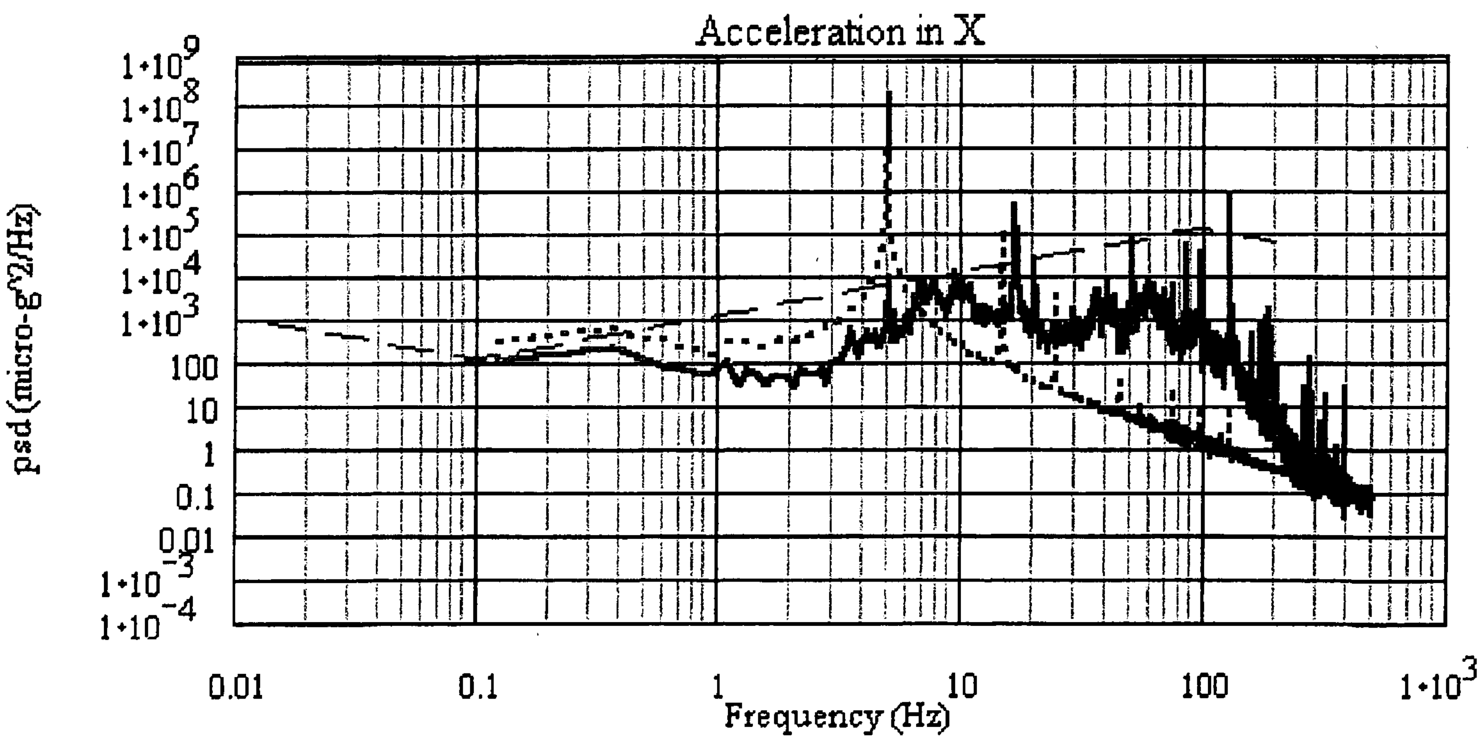
MIM-2 Isolation Transfer Function
Run 708162:1 0.3 Hz Cutoff Frequency



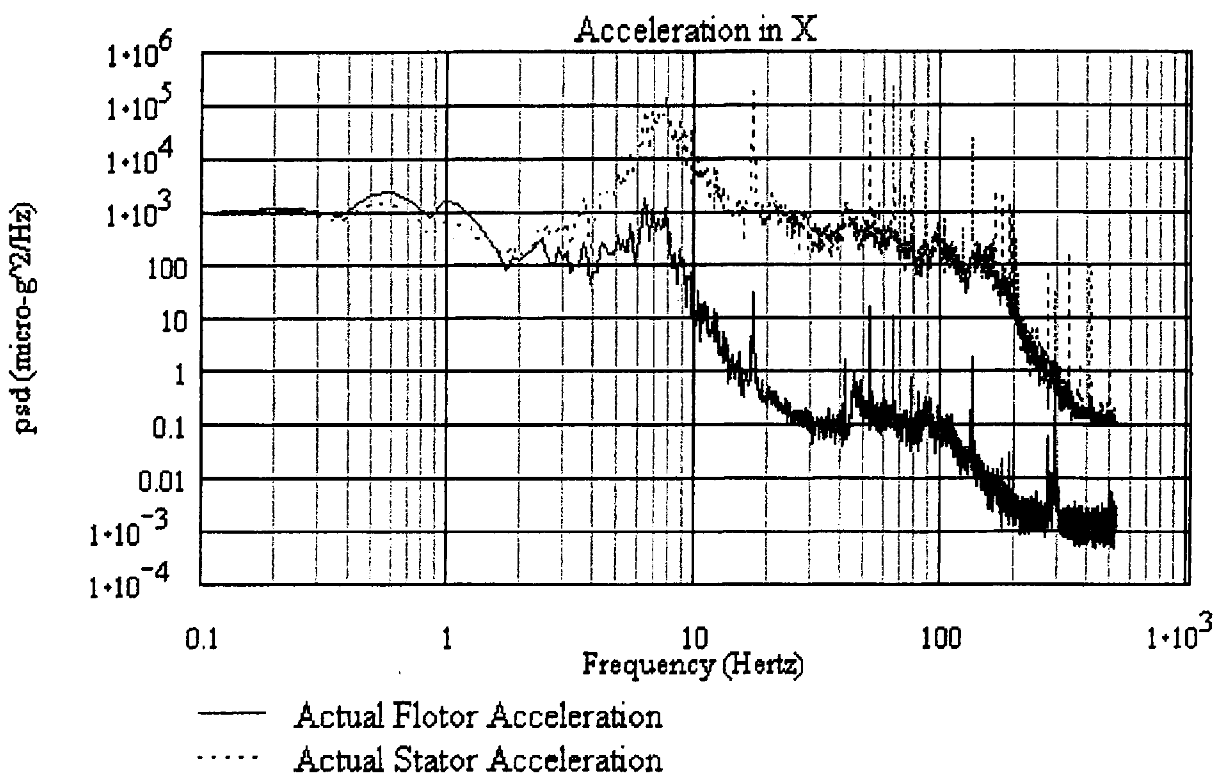
MIM Driven Mode - Random



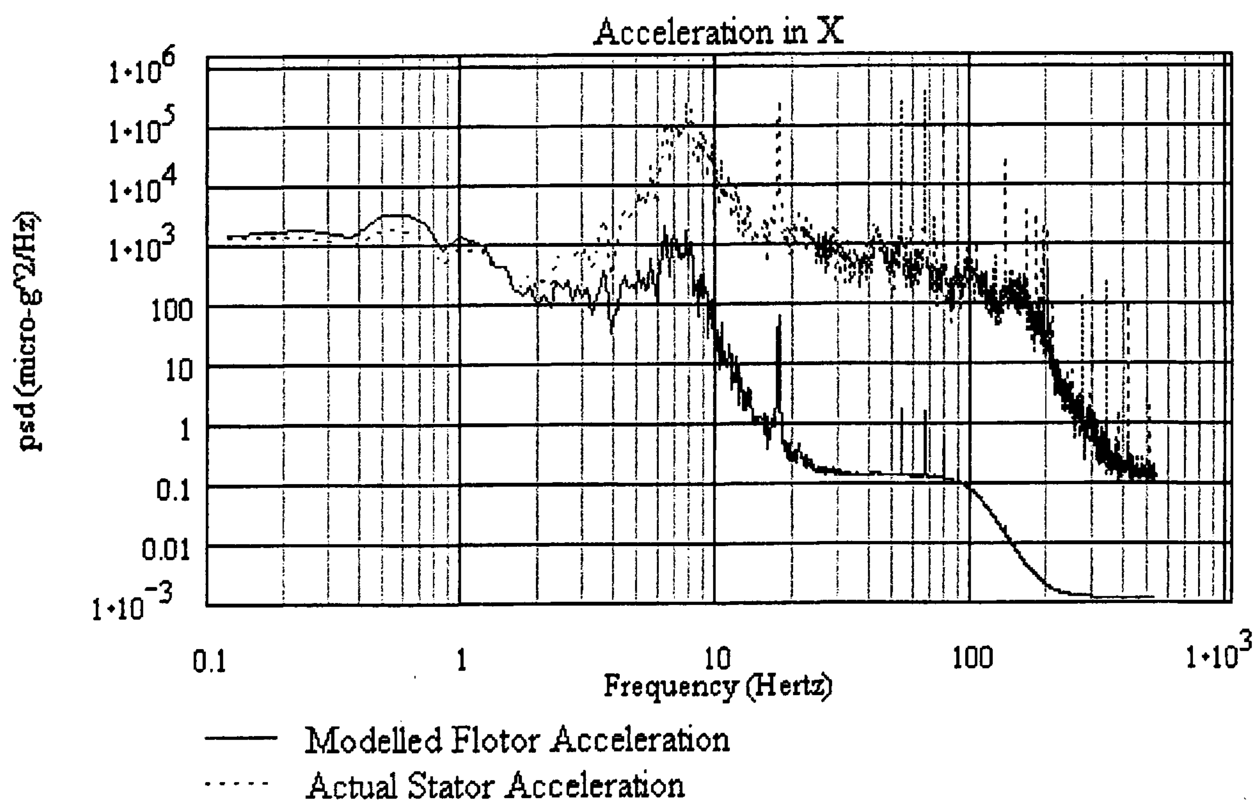
MIM Driven Mode - 5 Hz



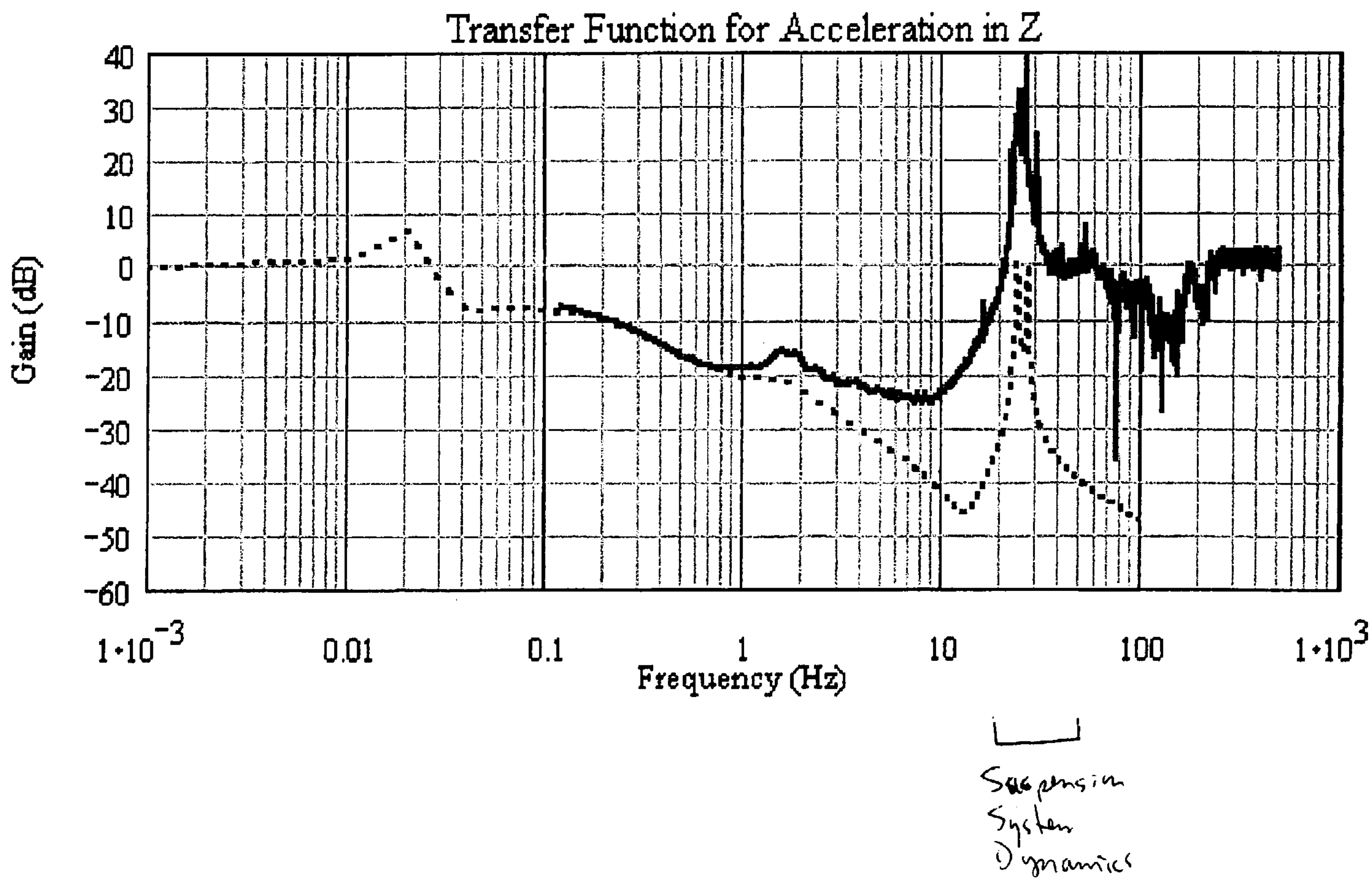
Measured Stator and Flotor Accelerations



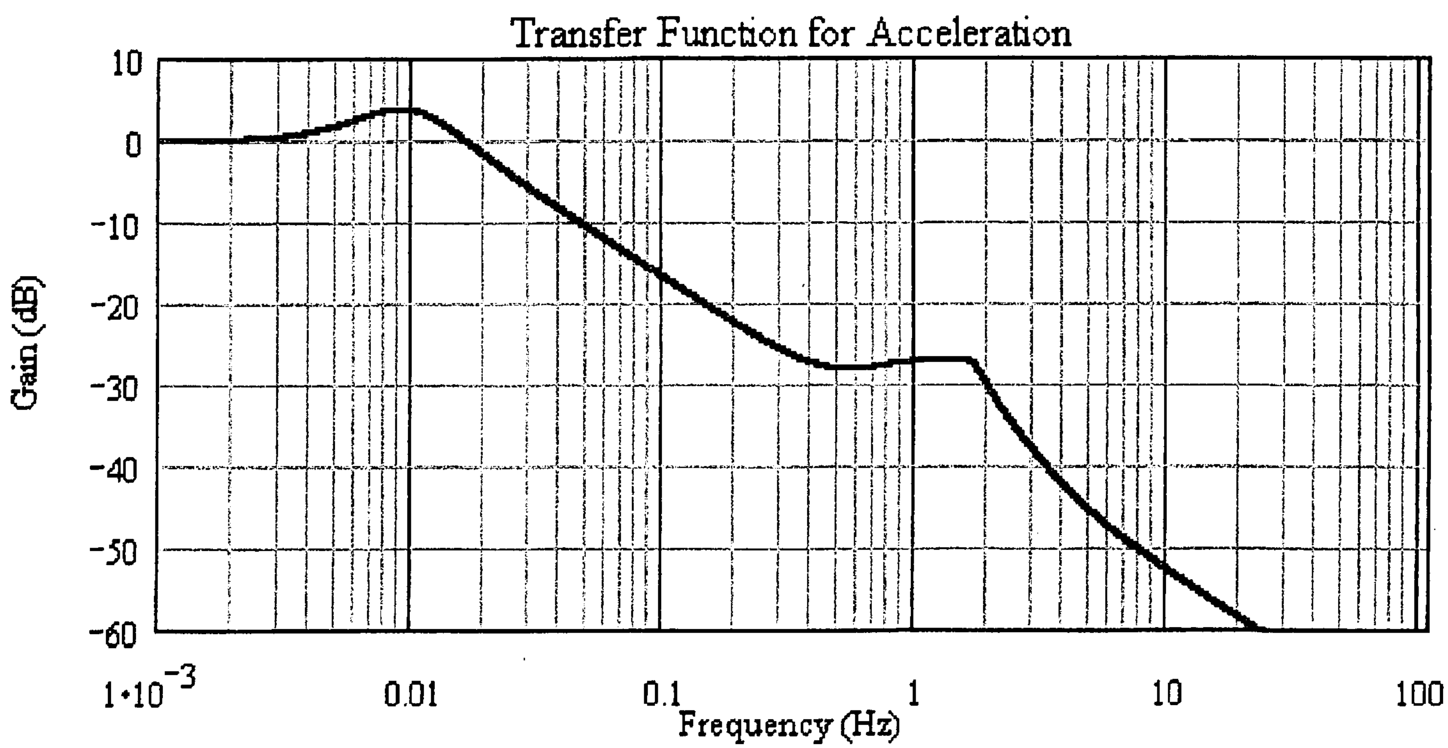
Measured Stator and Modeled Flotor Accelerations



Transfer Function between the Flotor and Stator Accelerations Obtained in Ground Testing with the MIM-2 Flotor Supported Using a Pendulous Support System Post STS-85



Predicted Transfer Function between the Flotor and Stator Accelerations for a Cutoff Frequency of 0.02 Hz.



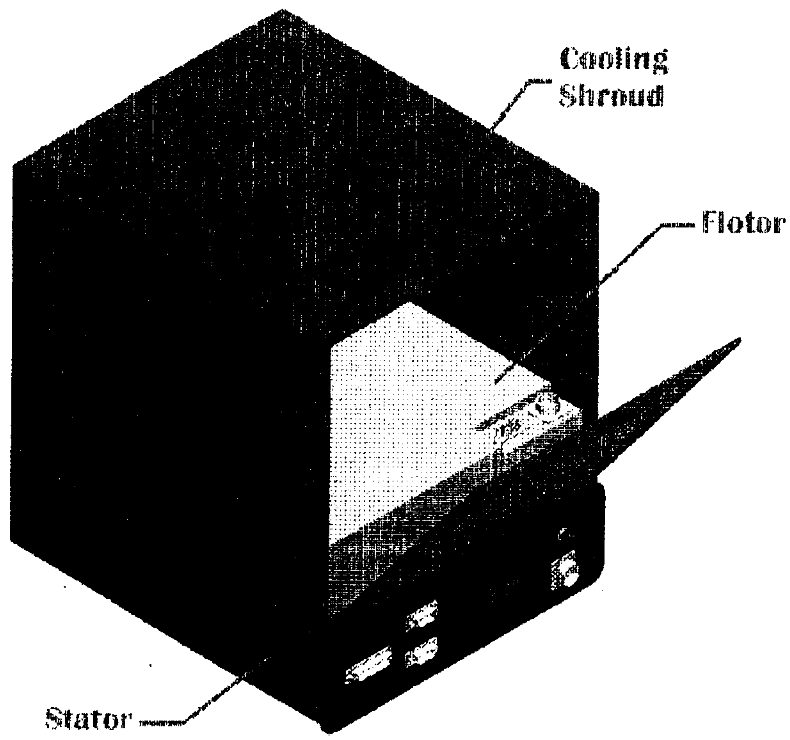
Comments on Acceleration Environment on Mir and the Shuttle

- Over most of the frequency band covered by the ISS specification for isolated racks the acceleration levels on the Mir are well below the specification
- The same holds true for the acceleration levels on the shuttle
- Coupled with the observed sensitivity of diffusion and internal fluid flow to g-jitter at these levels this indicates that the current specification for isolated racks on the ISS is not conservative for fluid based experiments
- Replicating some of these experiments to verify these observations should be given a high priority and should be done before all experiment hardware is installed on the ISS

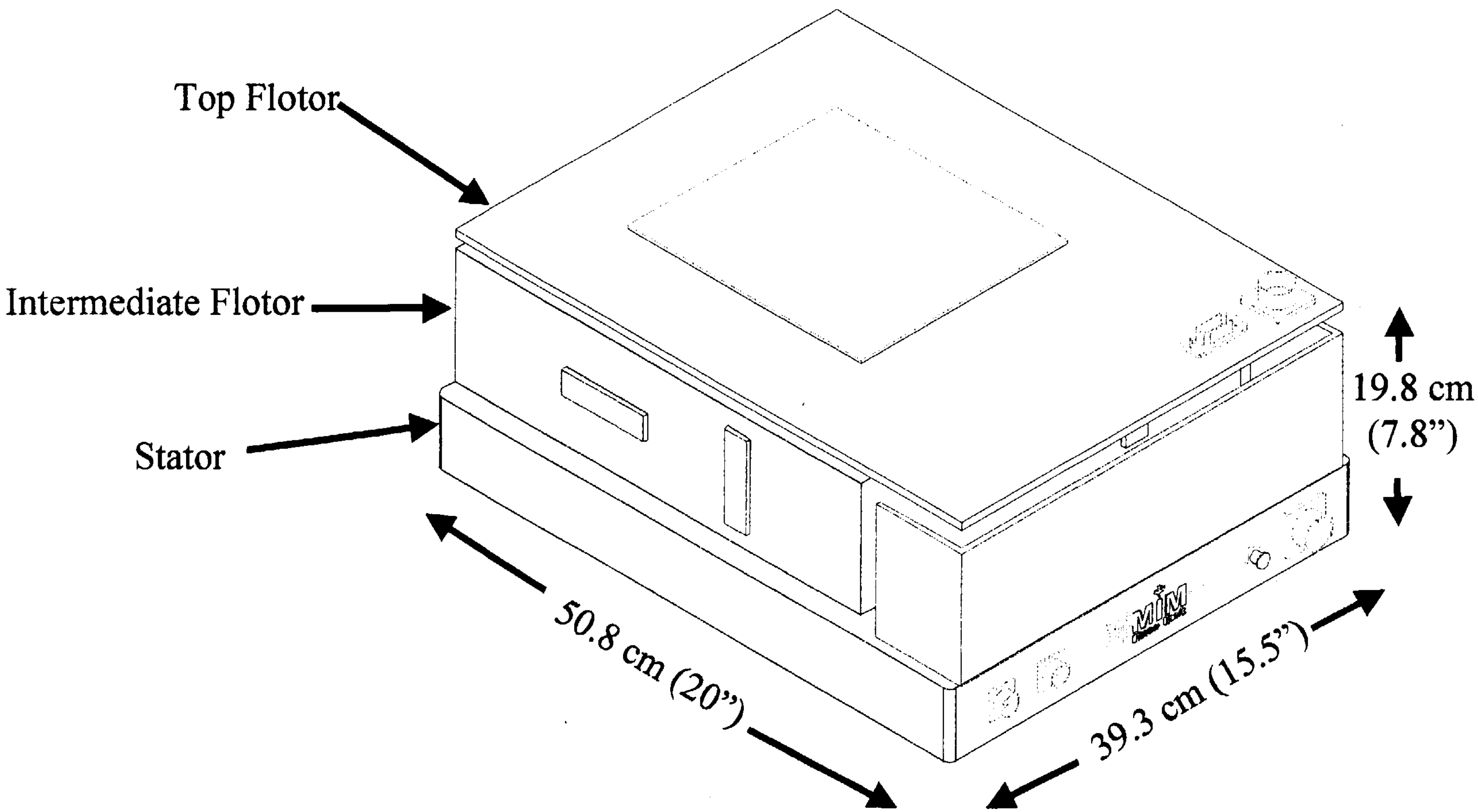
CSA Plans for Isolation Systems on the ISS

- MIM Base Unit (MIMBU)
  - Designed for EXPRESS using the volume of a double locker
  - Will support numerous locker sized experiments
- Microgravity Vibration Isolation Subsystem
  - Designed to be integral part of the ESA Fluid Science Laboratory
  - Will isolate the Facility Core Element

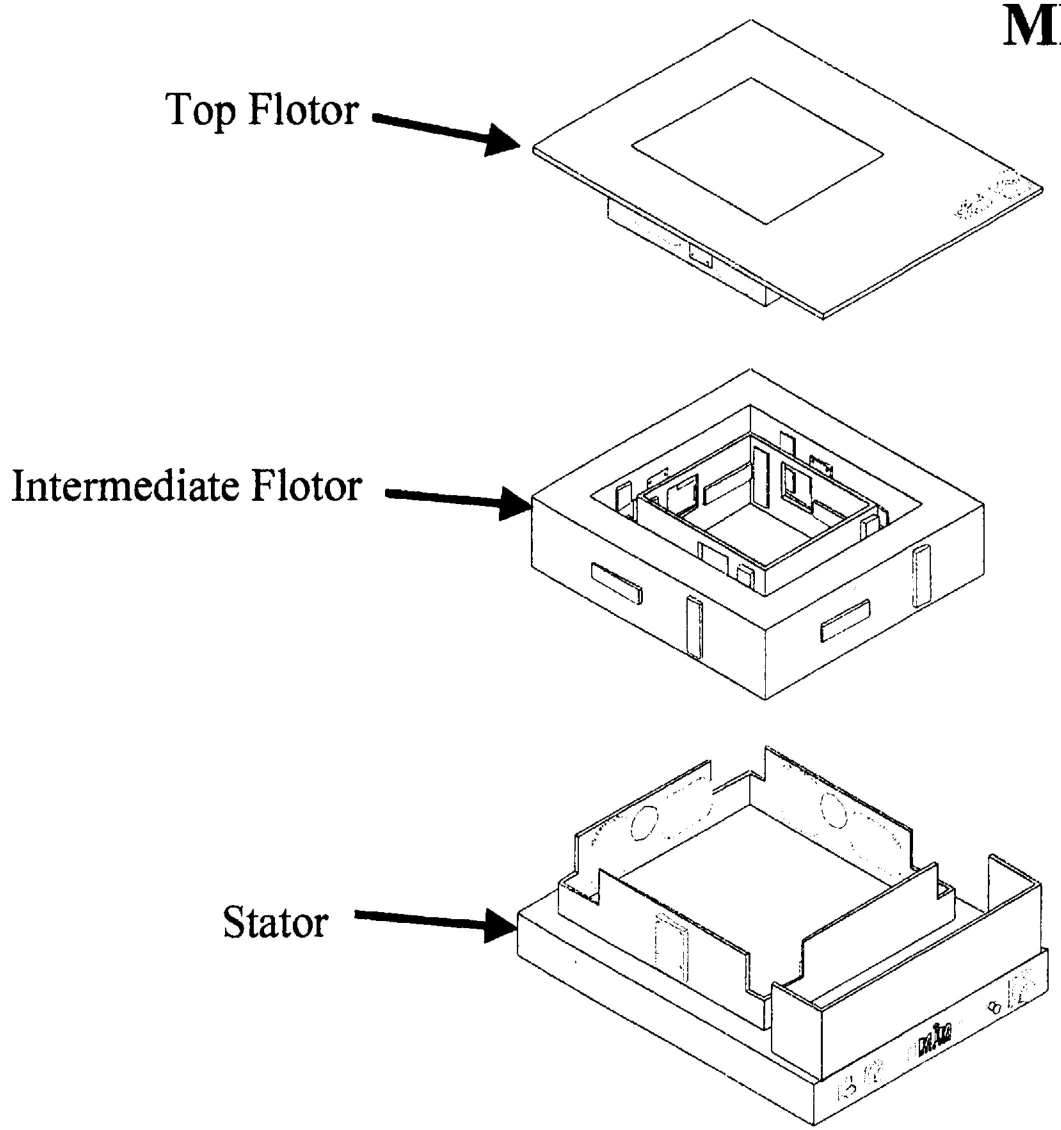
MIMBU Installed in Double Locker Sized Water Cooled Shroud

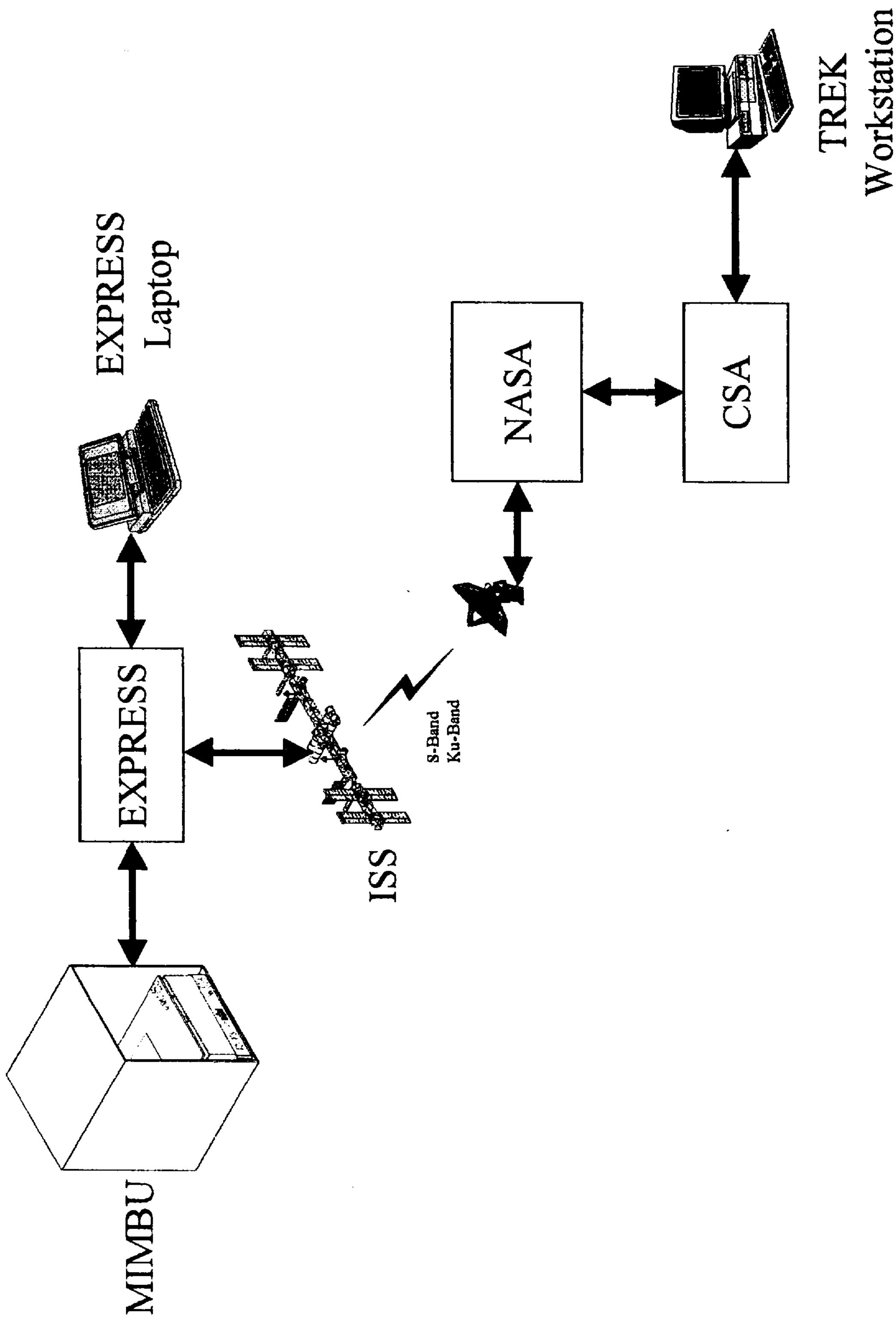


MIM Base Unit for ISS

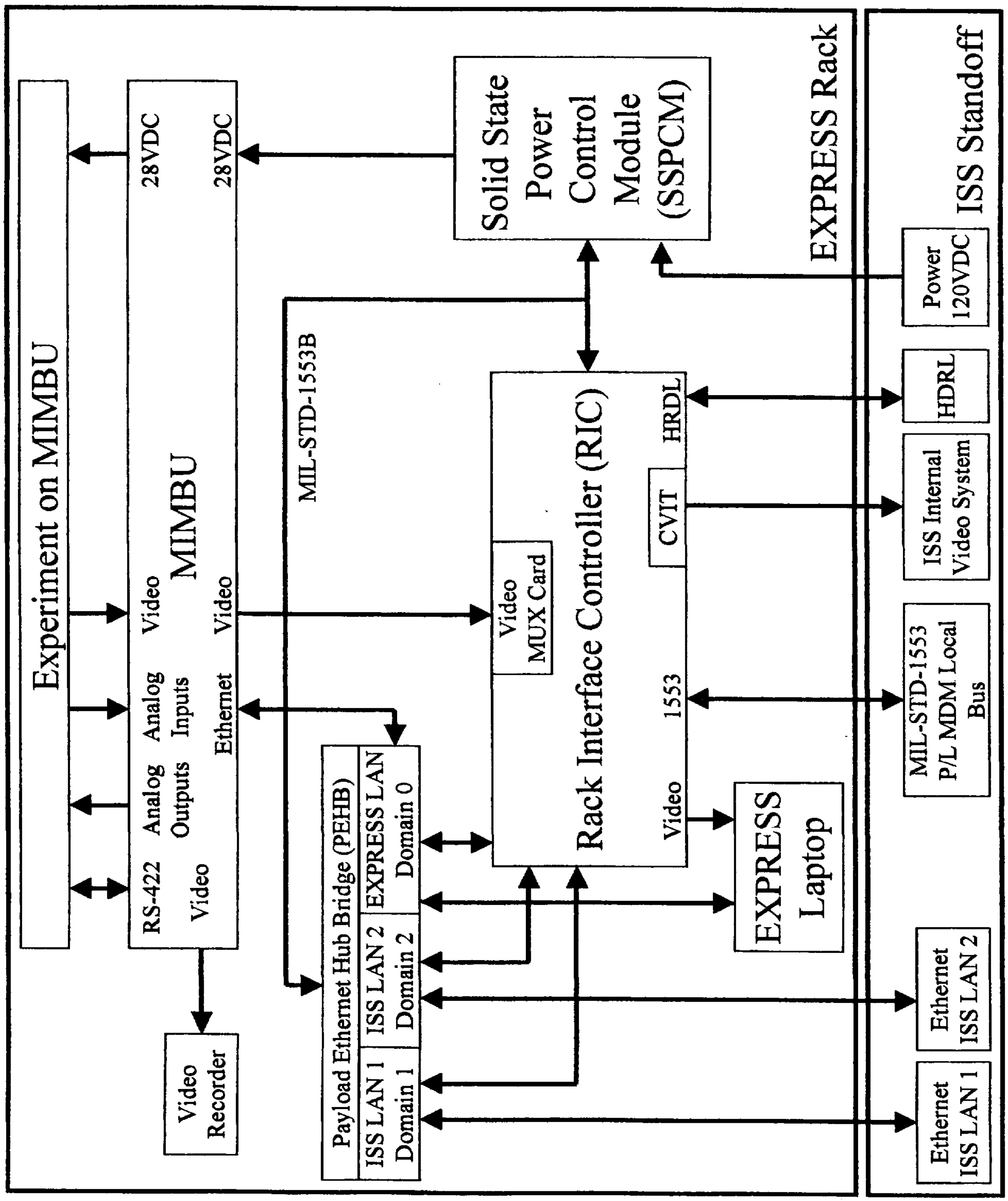


MIM Base Unit for ISS

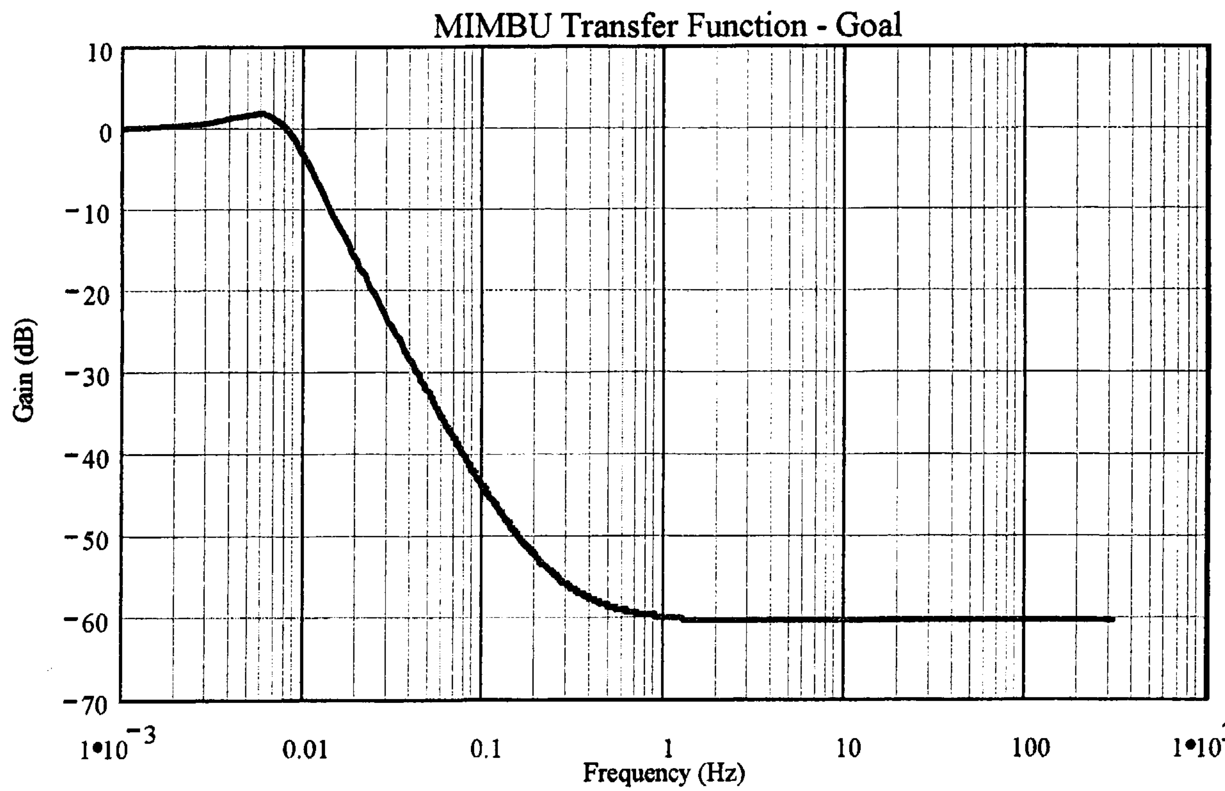




MIMBU
EXPRESS
EXPRESS
Laptop
ISS
S-Band
Ku-Band
NASA
CSA
TREK
Workstation


Experiment on MIMBU
MIMBU
28VDC
28VDC
Video
Analog Inputs
Analog Outputs
RS-422
Video
Video
Ethernet
Video Recorder
Solid State Power Control Module (SSPCM)
EXPRESS Rack
MIL-STD-1553B
Rack Interface Controller (RIC)
Video MUX Card
CVIT
HRDL
1553
Video
EXPRESS Laptop
Payload Ethernet Hub Bridge (PEHB)
ISS LAN 1 Domain 1
ISS LAN 2 Domain 2
EXPRESS LAN Domain 0
ISS Standoff
Power 120VDC
HDRL
ISS Internal Video System
MIL-STD-1553 P/L MDM Local Bus
Ethernet ISS LAN 2
Ethernet ISS LAN 1

MIMBU Performance Goal



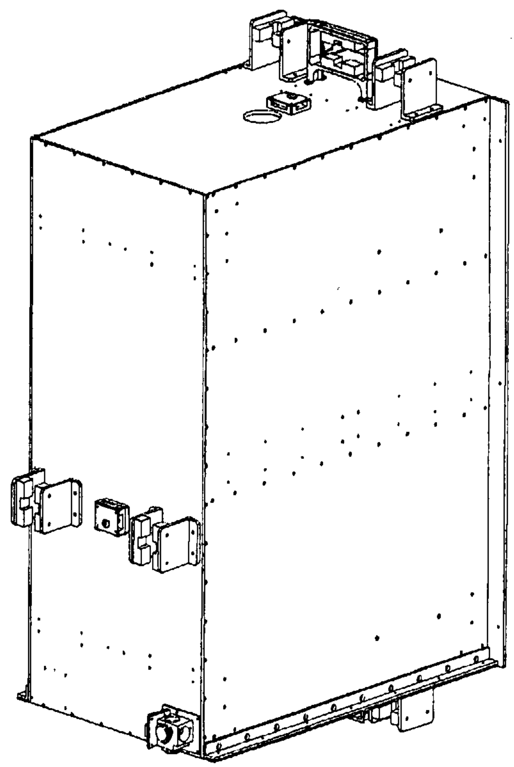
MIMBU Status

- Fairly detailed concept design is completed as is system models
- Two stage system based on MIM and Mini-MIM flew on Falcon parabolic flight aircraft in March 2000
  - Proof of control system stability
- System Requirements Completed
- Expect to have manufacturing contract in place in October 2000
- Currently Planned Payloads:
  - Gradient Furnace
  - Fluid Science Module
  - Protein Crystal Growth Module
  - DECLIC (CNES)

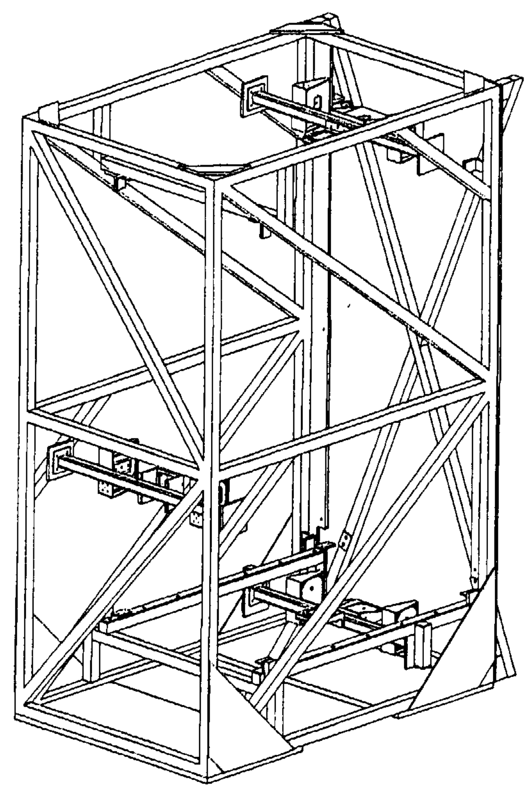
MVIS for the ESA FSL

- Isolates the Facility Core Element (FCE) from the ISPR
  - FCE houses the Experiment Container (EC) and data acquisition and diagnostic hardware
- EC is interchangeable
- Commanded through the FSL MCU

FSL FCE/MVIS KC-135 Engineering Model



FSL ISPR KC-135 Mockup



MVIS Status

- PDR completed in May 1999
- Fully functional engineering model flew on KC-135 in June 1999
  - examined modeling and control issues for multiple umbilical connections
- FM to be delivered in mid 2001
- Delivery to ISS expected in 2003

Issues for Science on ISS

- What are the required, science driven versus program driven, limits on vibration levels for fluid based experiments
- What levels will the ISS provide and is this information clearly available to the science community
  - without isolation
  - with isolation
- The NASA ISS program office accepted that isolation systems are required for the ISS
  - Has not reconciled the roles of rack level versus experiment level isolation
  - NASA plans to use rack level isolation
  - CSA (ESA and NASDA) will use experiment level isolation

221/29

2001019752512583

56 PS

MGMG #19

Paper Number: 21

US Lab microgravity tests: accelerations, transfer functions, comparisons with analyses

Otto Crenwelge
Dynacs Information & Applied Technology
Houston, Texas

Ed O'Keefe
The Boeing Company
Huntsville, Alabama

Mark Miller
The Boeing Company
Seattle, Washington

Wei-Joe Sun
The Boeing Company
Houston, Texas

Vinod Shekher
PDS Technical
Huntsville, Alabama

Microgravity measurements and tests were conducted on the US Lab (Destiny) at KSC in December 1999 and February 2000. The tests were conducted in three parts. Measurements were made of rack and structure accelerations and cavity sound pressures induced by the operation of intermittent and continuous USL equipment items, subsystems, and combined systems. Acoustical power-to-sound pressure and acoustical power-to-acceleration transfer functions were measured during operation of a calibrated sound power source with USL equipment shut down. And mechanical force-to-acceleration transfer functions were measured via application of calibrated hammer impulses and vibrator swept sine excitations to racks and structure with USL equipment shut down.

The data are being reduced in the form of narrowband power and energy spectral densities, transfer functions, and coherence functions and 1/3-octave band rms and peak spectra and transfer functions. Analytical predictions of accelerations, sound pressures, and transfer functions for the ground test configuration are being compared with the ground test data to determine the degree of conservatism inherent in the analyses. These correlations are producing confidence factors that will be applied to analytical predictions of on-orbit responses and transfer functions to obtain improved estimates of these quantities.

In addition, the effective sound power of the operating USL equipment systems will be obtained by extracting the acoustical power-to-sound pressure transfer functions from the measured sound pressures. These sound powers will then be used with the acoustical power-to-acceleration transfer functions to calculate the portion of the measured accelerations that were induced acoustically by the USL equipment. The portion of the measured accelerations that were induced mechanically by the USL equipment can then be computed by extracting the acoustically induced accelerations from the total measured accelerations. Finally, estimates of the effective mechanical forces of the operating USL equipment systems can be obtained by extracting the mechanical force-to-acceleration transfer functions from the mechanically induced accelerations.

This presentation discusses results to date and future plans. The US Lab test data represents the best measured data available to date to the ISS microgravity community and will be useful to both vehicle and payloads providers alike. The data illustrates the microgravity acceleration environment expected during operation of US Lab equipment that is identical to, or typical of, equipment being used in all ISS pressurized modules. Measured transfer functions are presented which provide confidence in element model predictions. Force and sound power disturbance functions to be extracted in the near future will provide much improved descriptions of these quantities than is currently available.

US Lab Microgravity Tests: Accelerations, Transfer Functions, Comparisons with Analyses

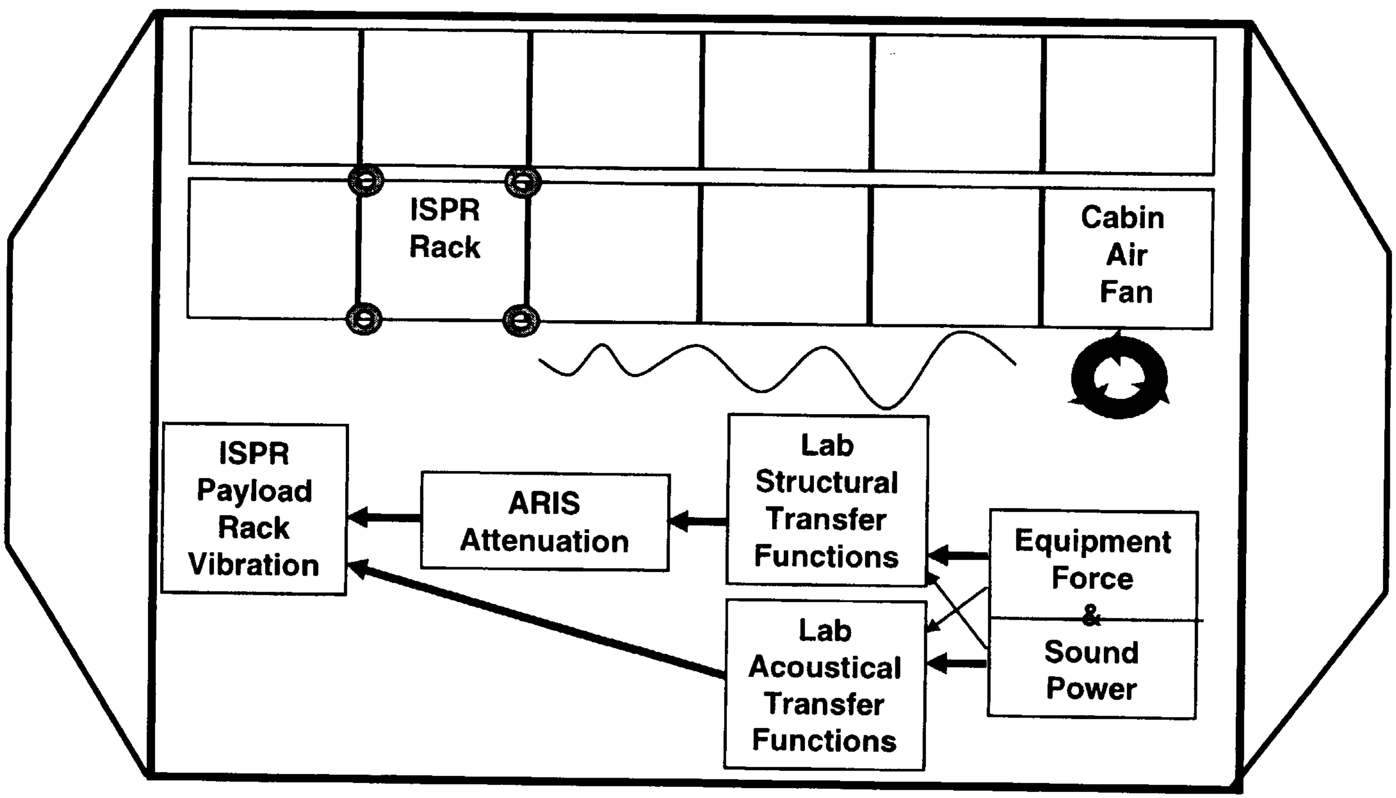
Otto Crenwelge
Ed O'Keefe
Mark Miller
Wei-Joe Sun
Vinod Shekher

19th Microgravity Measurements Group Meeting
11-13 July 2000

Dynacs Information & Applied Technology

BOEING

Microgravity Model:
Source - Path - Isolator - Receiver



Accelerations at payload locations result from the combined effects of source force & sound power, structural & acoustical transmission paths, and ARIS attenuation

Microgravity Test Objectives

- Measure and record structural acceleration and sound pressure data at selected USL locations induced by operating USL equipment items, subsystems, and combined systems of intermittent and continuous nature (11 equipment racks in 6A configuration with launch boundary conditions). Data has been used to:
    - Correlate (scale) analytical on-ground predictions of USL acceleration and sound pressure response induced by operating USL equipment
    - Extend experimental/analytical on-ground response scaling relationships to the USL on-orbit configuration
    - Support analytical predictions that the USL vibration environment meets microgravity requirements with USL equipment operating
- Measure and record structural acceleration and sound pressure data at selected USL locations induced by operating a calibrated acoustical power source with all USL equipment shut down. Data is being used to:
    - Obtain experimental on-ground acoustical-power-to-sound-pressure and acoustical-power-to-structural-acceleration transfer functions
    - Correlate (scale) analytical on-ground acoustical-power-to-sound-pressure and acoustical-power-to-structural-acceleration transfer functions
    - Use with the measured USL equipment induced sound pressures above to determine the effective sound power of USL operating equipment systems
    - Calculate the acoustically induced acceleration environment induced by operating USL equipment
    - Remove the calculated acoustically induced accelerations from the measured USL equipment induced accelerations above to yield the mechanically induced accelerations from operating USL equipment

MICROGRAVITY TEST OBJECTIVES (cont.)

- Measure and record structural acceleration data at selected USL locations induced by operation of calibrated mechanical sources (hand held vibrator and impulse hammer) with all USL equipment shut down. Data will be used to:
  - Obtain experimental on-ground mechanical-force-to-structural-acceleration transfer functions
  - Correlate (scale) analytical on-ground mechanical-force-to-structural-acceleration transfer functions
  - Determine the effective mechanical force of USL operating equipment systems by deconvolving the force-to-acceleration transfer functions from the USL equipment mechanically induced accelerations calculated above
- Detailed data reduction, evaluation, and correlation with analytical predictions is being conducted post-test to satisfy the above objectives

US Lab Disturber Equipment

	Bay 1	Bay 2	Bay 3	Bay 4	Bay 5	Bay 6
Ceiling X1	**ISPR** AAA & Heat Xchg Coldplate - 6 RFCA Vacuum Valve	**ISPR** AAA & Heat Xchg Coldplate - 6 RFCA Vacuum Valve	**ISPR** AAA & Heat Xchg Coldplate - 6 RFCA Vacuum Valve	**ISPR** AAA & Heat Xchg Coldplate - 6 RFCA Vacuum Valve	**ISPR** AAA & Heat Xchg Coldplate - 6 RFCA Vacuum Valve	**DDCU-2 Avionics** 2 Coldplate -1 Coldplate -8 Man Flow Cntrl Valve
Strbd	**ISPR** AAA & Heat Xchg Coldplate - 6 Light Fixture RFCA Vacuum Valve	**ISPR** AAA & Heat Xchg Coldplate - 6 Light Fixture RFCA Vacuum Valve	**ISPR** AAA & Heat Xchg Coldplate - 6 Light Fixture RFCA Vacuum Valve	**ISPR** AAA & Heat Xchg Coldplate - 6 Light Fixture RFCA Vacuum Valve	**MSS Avionics** 3 Coldplate -8 Manl Flow Cntrl Valve Light Fixture RWS VTR	**Mod Temp TCS Cabin Air NIA** PPA Sys Flow Cntrl Assy 2 Man Flow Cntrl Valve THC Cabin Fan& Motor Light Fixture Coldplate - 4 Inlet ORU Water Separator (Pump, Fan, Motor) Inlet ORU (Fan & Motor) TCCV (Stepper Motor) Heat Exchanger
Floor X3	**Avionics-2** 4 Coldplate -8 Manual Flow Cntrl Valve	**Avionics3** 5 Coldplate -8 Manual Flow Cntrl Valve	**ISPR Window** AAA & Heat Xchg Coldplate -6 RFCA Vacuum Valve	**CHeCS** AAA & Heat Xchg Coldplate-6 Manual Flow Cntrl Valve VOA	**Avionics-1** 4 Coldplate-8 Man Flow Cntrl Valve	**ARS** CDRA Blower CDRA 2-stage pump MCA (Motor&Pump) TCCS Blower coldplate (disconnected) 2 Man Flow Cntrl Valve AAA Heat Xchg
Port X4	**ISPR** AAA & Heat Xchg Coldplate - 6 RFCA Light Fixture Vacuum Valve	**ISPR** AAA & Heat Xchg Coldplate - 6 RFCA Light Fixture Vacuum Valve	**DDCU-1 Avionics** 2 Coldplate -1 Coldplate - 8 Man Flow Cntrl Valve Light Fixture	**ISPR** AAA & Heat Xchg Cold Plate - 6 RFCA Light Fixture Vacuum Valve	**MSS Avionics** 3 Coldplate -8 Manl Flow Cntrl Valve Light Fixture VTR	**Low Temp TCS Cabin Air NIA** PPA Sys Flow Cntrl Assy 2 Man Flow Cntrl Valve THC Cabin Fan& Motor Light Fixture Coldplate - 4 Inlet ORU Water Separator (Pump, Fan, Motor) Inlet ORU (Fan & Motor) TCCV (Stepper Motor) Heat Exchanger

Forward Endcone
2 IMV Fan
2 IMV Fan Inlet
Coldplate -1
Coldplate -4
2 Coldplate -6
3 Coldplate -7
Coldplate - 8
Coldplate -9
Manual Flow Cntrl Valve
2-Water Vents
PCA Vent
ACS Vent, Valve, Panel
ARS SDS Valve

Aft Endcone
1 - IMV Fan
1 - IMV Outlet
Coldplate -1
Coldplate -4
Coldplate -6
Coldplate -7
Coldplate -8
Coldplate -10
Manual Flow Control Valve
2 - RFCA
3 - 3way ITCS
VRS Vent
VES Vent
2-Heat Xchng (CTB)
2-Heat Xchng Mod/Low temp Heat Xchngr

11-13 July 2000 — **19th Microgravity Measurements Group Meeting** — Crenwelge/O'Keefe/Miller/Sun/Shekher

Equipment Operating in All Source, CDRA, & Baseline Runs

- Run 65 – All USL Equipment (except CDRA) plus Baseline (see Run 66)
  - LAF6 – ARS
    - TCCS Blower
    - AAA Fan
    - MCA Pump
    - Coldplate (disconnected)
    - Manual Flow Control Valve (NQ)
  - LAP6 – Low Temp TCS & THC
    - TCS PPA Pump
    - THC Cabin Air Fan
    - Water Separator
    - Coldplate
    - SFCA Valve
    - TCCV (set)
    - Manual Flow Control Valve (NQ)
  - LAS6 – Mod Temp TCS & THC
    - TCS PPA Pump
    - THC Cabin Air Fan (not operating)
    - Water Separator
    - TCCV (set)
    - Coldplate
    - SFCA Valve
    - Manual Flow Control Valve (NQ)
  - LAC6 – DDCU Avionics
    - 3 Coldplate
    - Manual Flow Control Valve (NQ)
  - LAS5 – MSS Avionics
    - 3 Coldplate
    - Manual Flow Control Valve (NQ)
    - 2 Video Tape Recorders (not operating)
    - Robotic Work Station (not operating)
  - LAF5 – Avionics 1
    - 4 Coldplate
    - MDM Disc Drive
    - Manual Flow Control Valve (NQ)
  - LAP5 – MSS Avionics
    - 3 Coldplate
    - Manual Flow Control Valve (NQ)
    - 2 Video Tape Recorders (not operating)
  - LAF4 – CheCS
    - VOA (not operating)
    - Defibrillator (not operating)
    - AAA Fan (not operating)
  - LAP3 DDCU Avionics 1
    - 3 Coldplate
    - RFCA Valve
    - Manual Flow Control Valve (NQ)
  - LAF2 – Avionics 3
    - 5 Coldplate
    - RFCA Valve
    - MDM Disc Drive
    - Manual Flow Control Valve (NQ)
  - LAF1 – Avionics 2
    - 4 Coldplate
    - 2 MDM Disc Drive
    - Manual Flow Control Valve (NQ)
  - Aft Endcone
    - IMV Fan
    - 2 IMV Valve
    - 8 Coldplate
    - Manual Flow Control Valve (NQ)
    - Vacuum Exhaust Vent (not operating)
    - CO2 Vent (not operating)
  - Forward Endcone
    - 2 IMV Fan
    - 2 IMV Valve
    - 9 Coldplate
    - RFCA Valve
    - Manual Flow Control Valve (NQ)
    - Water Vent (not operating)
  - X1 Standoff – Starboard/Ceiling
    - 3 THC Duct Outlet
  - X2 Standoff – Starboard/Floor
    - 3 THC Duct Inlet
    - AR Tubing (not operating)
    - Water Recovery Tubing
  - X3 Standoff – Port/Floor
    - 3 THC Duct Inlet
    - VES Duct
    - N2 Flex Hose
    - ACS N2/O2 Tubing
    - TCS Pump Bypass Tubing
    - ARS Tubing
    - Water Recovery Tubing
  - X4 Standoff – Port/Ceiling
    - 3 THC Duct Outlet
    - TCS Tubing
- Run 66 – Baseline of Run 65
  - External Support Equipment
    - 2Chiller Pumps on Cooling Servicer
    - Large Vacuum Pump
    - Power Supplies
    - Computers
- Run 11 – CDRA Equipment plus Baseline (see Run 11a)
  - LAF6 – ARS
    - CDRA Pump
    - CDRA Fan
    - TCCS Blower (not operating)
    - AAA Fan
    - MCA Pump (not operating)
    - Coldplate (disconnected)
    - Manual Flow Control Valve (NQ)
  - LAP6 – Low Temp TCS & THC
    - THC Cabin Air Fan
- Run 11a – Baseline for Run 11
  - External Support Equipment
    - 2 GSE Coolant Circulation Pumps
    - 2Chiller Pumps on Cooling Servicer
    - Large Vacuum Pump
    - Power Supplies

Computers

Intermittent Source Tests

Test Case	Expected Duration	Description
Configuration 1 (USL Open-Hatch Acoustics)		
Phase 1, Background Noise	**4 hours**	**Collect noise measurements with the USL unpowered and both hatches open.**
Phase 2, Reverberation Time	**8 hours**	**Collect noise-level decay measurements with the USL unpowered and both hatches open; Perform background noise measurement between each run as required. (uses sound power source)**
USL Forward Run 1		
USL Forward Run 2		
USL Forward Run 3		
USL Forward Run 4		
USL Aft Run 1		Add 2 additional runs for Aft Lab Position:
USL Aft Run 2		USL Aft Run 5 (60 dB for 5 minutes)
USL Aft Run 3		USL Aft Run 6 (60 dB for 5 minutes)
USL Aft Run 4		
Phase 3, Baseline Noise	**4 hours**	**Collect noise measurements with the core USL powered and both hatches covered with BISCO-wrap curtains.**
Phase 4, Intermittent Noise Emissions	**48 hours**	**Collect intermittent noise measurements with the core USL powered and both hatches covered with BISCO-wrap curtains; Collect baseline noise measurement between each test case.**
Test Case 1, ACS Pressure Control Panel	4 hours	Pressurize N2 lines with the FE 1411 only during Condition 3; Collect baseline noise measurement between each test condition as required.
Condition 1, OIV (without gas flow)		*Collect noise measurement during OIV cycling open and during OIV cycling closed.*
Condition 2, NIV (without gas flow)		*Collect noise measurement during NIV cycling open and during NIV cycling closed.*
Condition 3, NIV (with gas flow)		*Collect noise measurement during NIV cycling open and during NIV cycling closed.*
Test Case 2, ITCS Rack Flow Control Assemblies	4 hours	Allow ITCS coolant flow with hydraulic load applied to the following RFCAs using the FE 1247-1; Collect baseline noise measurement between each test condition as required; Collect noise measurements both during RFCA flow change transitions and steady-stat
Condition 1, Airlock LT RFCA		*250 pph/8.5 psid; 750 pph/8.0 psid*
Condition 2, ISPR LAC3 RFCA		*250 pph/8.5 psid; 750 pph/8.0 psid*
Condition 3, ISPR LAF3 RFCA		*250 pph/8.5 psid; 500 pph/9.0 psid; 750 pph/8.0 psid; 1000 pph/8.0 psid*
Condition 4, ISPR LAS3 RFCA		*250 pph/8.5 psid; 750 pph/8.0 psid*
Test Case 3, AR CO2 Vent Valves	4 hours	Collect noise measurements; Collect baseline noise measurement between each test condition as required.
Condition 1, Aft Endcone CO2 Vent Valve		*CVV A5201*
Condition 2, AR Rack CO2 Vent Valve		*CVV A5011*
Test Case 4, AR 3-Way SDS Valves	4 hours	Collect baseline noise measurement between each test condition as required; Collect switching noise measurements:
Condition 1, A5111 SDS Valve		*Position A to Position B; Position B to Position A*
Condition 2, A5112 SDS Valve		*Position A to Position B; Position B to Position A*
Condition 3, A5113 SDS Valve		*Position A to Position B; Position B to Position A*
Condition 4, A5114 SDS Valve		*Position A to Position B; Position B to Position A*
Test Case 5, ITCS System Flow Control Assemblies	4 hours	Collect baseline noise measurement between each test condition as required. Collect noise measurements both during SFCA transitions and steady-state flow setpoints:
Condition 1, LTTCS SFCA		*11 psid; 11 psid to 7 psid; 7 psid; 7 psid to 11 psid*
Condition 2, MTTCS SFCA		*11 psid; 11 psid to 7 psid; 7 psid; 7 psid to 11 psid*
Test Case 6, NIA Pressure Relief Valve	4 hours	Pressurize LT PPA NIA using the FE 1411.
Condition 1, LT NIA Pressure Relief Valve		*Collect noise measurement when valve is manually opened.*
Test Case 7, NIA Pressure Vent Valve	4 hours	Pressurize the MT PPA NIA using the FE 1411.
Condition 1, MT NIA Pressure Vent Valve		*Collect noise measurement when valve is commanded open.*
Test Case 8, ITCS Loop Crossover Assembly	N/A	Noise measurment from this intermittent noise source is collected during ITCS subsystem noise test case.
Test Case 9, ITCS 3-Way Mix Valves	4 hours	Collect baseline noise measurement between each test condition as required.
Condition 1, Original-to-Fully Conditioned Transition		*Collect noise measurement over peiod containing 17 second 3 WMV transition.*
Condition 2, Fully Conditioned-to-Full Bypass Transition		*Collect noise measurement over peiod containing 20 second 3 WMV transition.*
Condition 3, Full Bypass-to-Original Transition		*Collect noise measurement over peiod containing 17 second 3 WMV transition.*
Test Case 10, THC IMV Valves	4 hours	Collect baseline noise measurement between each test condition as required.
Condition 1, Aft Starboard IMV Valve		*Collect noise measurment during IMV cycling open and during IMV cycling close*
Condtion 2, Aft Port IMV Valve		*Collect noise measurment during IMV cycling open and during IMV cycling close*
Condition 3, Forward Starboard IMV Valve		*Collect noise measurment during IMV cycling open*
Condition 4, Forward Port IMV Valve		*Collect noise measurment during IMV cycling open and during IMV cycling close*
Test Case 11, ACS Payload NIV	4 hours	
Condition 1, Payload NIV (without gas flow)		*Collect noise measurement during Payload NIV cycling open and during Payload NIV cycling closed.*
Test Case 12, THC Process Air Valve	4 hours	
Condtion 1, PAV A5200		
Test Case 13, Video Tape Recorder	4 hours	Power Robotic Workstation.
Condition 1, VTR1		*Collect noise measurement during fast forward, reverse, and play.*
Test Case 14, ATU	N/A	Noise measurement from this intermittent noise source is collected during the element-level noise phase.

Continuous Source Tests

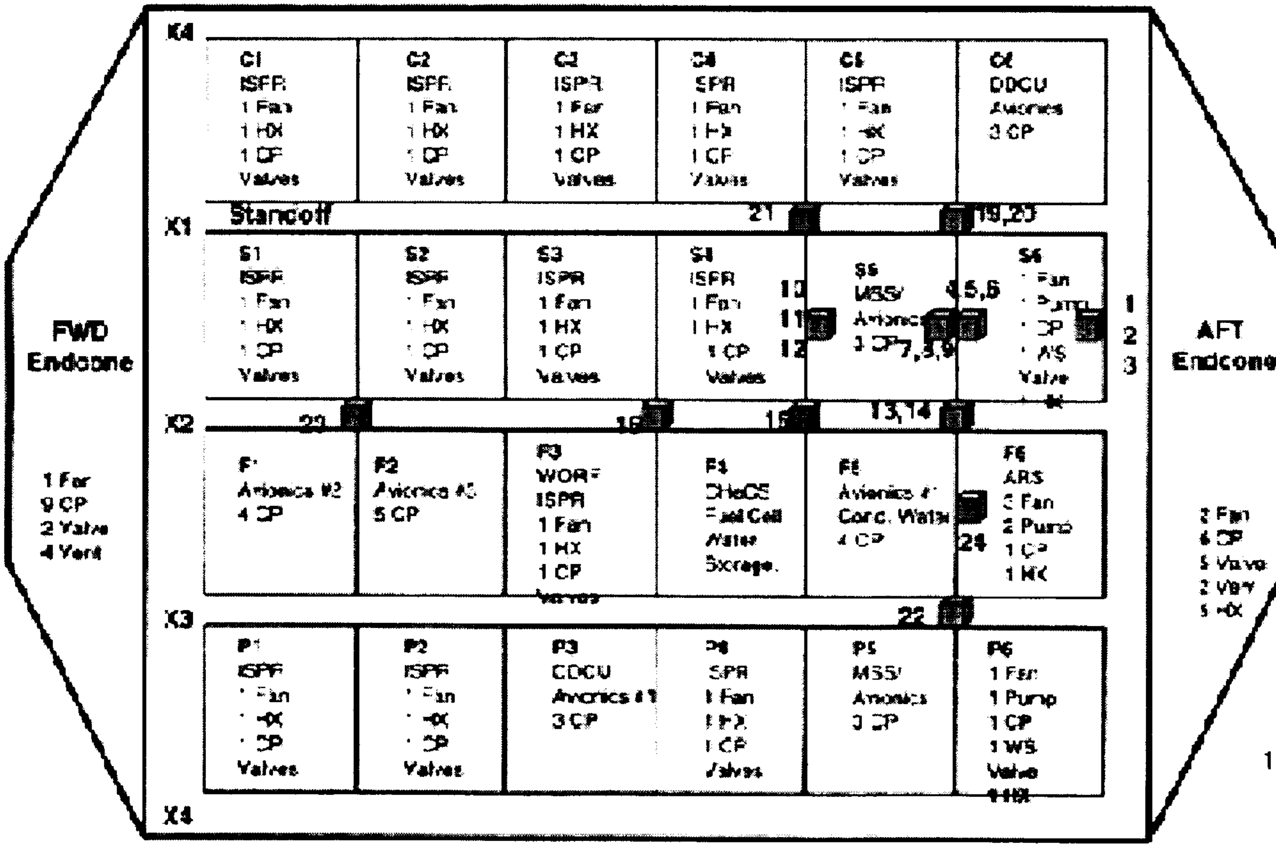
Test Case	Expected Duration	Description
Configuration 2 (USL Closed-Hatch Acoustics)		
Phase 1, Background Noise	**4 hours**	**Collect noise measurements with the USL unpowered and both hatches closed.**
Phase 2, Reverberation Time	**8 hours**	**Collect noise-level decay measurements with the USL unpowered and both hatches closed.**
USL Forward Run 1		
USL Forward Run 2		
USL Forward Run 3		
USL Forward Run 4		
USL Aft Run 1		Add 2 additional runs for Alt Lab Position:
USL Aft Run 2		USL Alt Run 5 (50 dB for 5 minutes)
USL Aft Run 3		USL Alt Run 6 (60 dB for 5 minutes)
USL Aft Run 4		
Phase 3, Baseline Noise	**4 hours**	**Collect noise measurements with the core USL powered and both hatches closed.**
Phase 4, Subsystem Noise	**28 hours +**	**Collect subsystem noise measurements with the core USL powered and both hatches closed; Perform baseline noise measurements between each test case.**
Test Case 1, General Luminary Assemblies Noise	4 hours	Collect noise measurement when the GLAs are activated to show that there is no increase in USL noise level.
Condition 1, GLA Activation		
Test Case 2, THC Noise	8 hours +	Perform baseline noise measurement between each test condition as required. Collect noise measurement at different fan speeds:
Condition 1, Single LAP6 CCAA Noise	For each condition, run	*6200 rpm*; 6700 rpm**; 7200 rpm****
Condition 2, Single LAS6 CCAA Noise	5 minutes at nominal	*6200 rpm*; 6700 rpm**; 7200 rpm****
Condition 3, Dual CCAA Noise	speed	*Nominal Dual Operation Speed.*
** if resonant frequency collect noise measurements at 6130 rpm; 6060 rpm; 5990 rpm; 6270 rpm; 6340 rpm; 6410 rpm.*		
*** if resonant frequency collect noise measurements at 6630 rpm; 6560 rpm; 6490 rpm; 6770 rpm; 6840 rpm; 6910 rpm.*		
**** if resonant frequency collect noise measurements at 7130 rpm; 7060 rpm; 6990 rpm; 7270 rpm; 7340 rpm; 7410 rpm.*		
Test Case 3, IMV Noise	4 hours	Perform baseline noise measurement between each test condition as required.
Condition 1, Aft Port IMV Fan	Same as Test Case 2	*Collect Noise Measurement after Fan Activation.*
Condition 2, Forward Starboard IMV Fan		*Collect Noise Measurement after Fan Activation.*
Condition 3, Forward Port IMV Fan		*Collect Noise Measurement after Fan Activation.*
Condition 4, All IMV Fans		*Collect Noise Measurement after Fan Activations.*
Test Case 4, ITCS Noise	8 hours	Perform baseline noise measurement between each test condition as required.
Condition 1, Single MT ITCS (LAS6) PPA Noise	Same as Test Case 2	*Collect Single LT Noise measurements at the following pump speeds: 18,900 rpm; 18,000 rpm; 17,000 rpm; 16,000 rpm; 15,000 rpm*
Condition 2, Single LT ITCS (LAP6) PPA Noise		*Collect noise measurement when LCA transitions from Single MT to Single LT; Collect Single MT Noise measurements at the following pump speeds: 18,900 rpm, 18,000 rpm; 17,000 rpm; 16,000 rpm; 15,000 rpm; 14,000 rpm; and 13,000 rpm.*
Condition 3, Dual ITCS (LAS6&LAP6) PPA Noise		*Collect noise measurement when LCA transitions from Single LT to Dual; Collect Dual Mode Noise measurements at the following default pump speeds.*
Test Case 5, AR Rack Noise	N/A	Noise measurement from this subsystem noise source is collected during the element-level noise phase
Phase 5, Element-Level Noise	**24 hours**	**Low Temperature coolant is used in the ITCS LTL and LAP6 CCAA will be condensing, i.e. USL rotation to port-side down is required.**
Test Case 1, Initial Startup		Core USL is activated; Baseline noise measurement is collected; LAP6 CCAA, IMV, and GLA are activated.
Condition 1, Common Core Activation with Flight PPAs		
Condition 2, LAP6 CCAA Activation		
Condition 3, IMV Activation		
Condition 4, GLA Activation		
Test Case 2, AR Rack Activation		Baseline measurement is activated prior to AR Rack Startup.
Condition 1, Rack Power and FDS		*AAA noise measurements collected at default, minimum and maximum speeds.*
Condition 2, MCA		*Noise measurement collected after MCA startup.*
Condition 3, TCCS		*Noise measurement collected after TCCS startup and after fully warmed-up.*
Condition 4, CDRA		*Noise measurement collected after CDRA startup and during half cycles while waiting for the TCCS to reach fully warmed up state.*
Test Case 5, CHeCS Rack Activation	For Test Case 7, run 5	*AAA noise measurements collected at default, minimum and maximum speeds; then CHeCS is deactivated.*
Test Case 6, C&W Activation	minutes at nominal	*Activate ATU & CWP; Collect noise measurement during commanded CWP "self-test"; Deactivate ATU & CWP.*
Test Case 7, Final Element-Level Noise Measurements	conditions	*Collect final element-level noise measurement; Shutdown USL.*

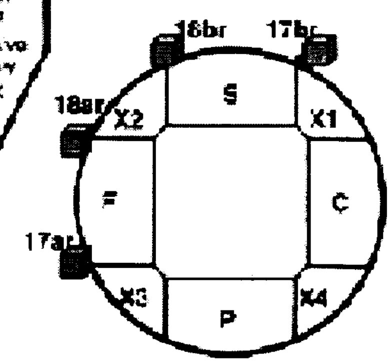
9

Locations of US Lab Microgravity Accelerometers

N ... Accel Locator (1-16)	Fl# ... Floor Rack #	n ... Standoff Number (1-4)
NX,NY,NZ ... SS X,Y,Z Direction of N	RPo ... Right Post	XnSO ... Standoff n
NR ... Radial (Normal) Direction of N	LPo ... Left Post	S6/S5 ... Rack Interface Locations
# ... Rack Number (1-6)	RPa ... Right Side of Panel	XnLb ... Bottom Longeron for XnSO
S# ... Starboard Rack #	LPa ... Left Side of Panel	XnLt ... Top Longeron for XnSO
P# ... Port Rack #	M ... Mid Height of Rack	br ... before Rotation
Accelerometer		ar ... after rotation

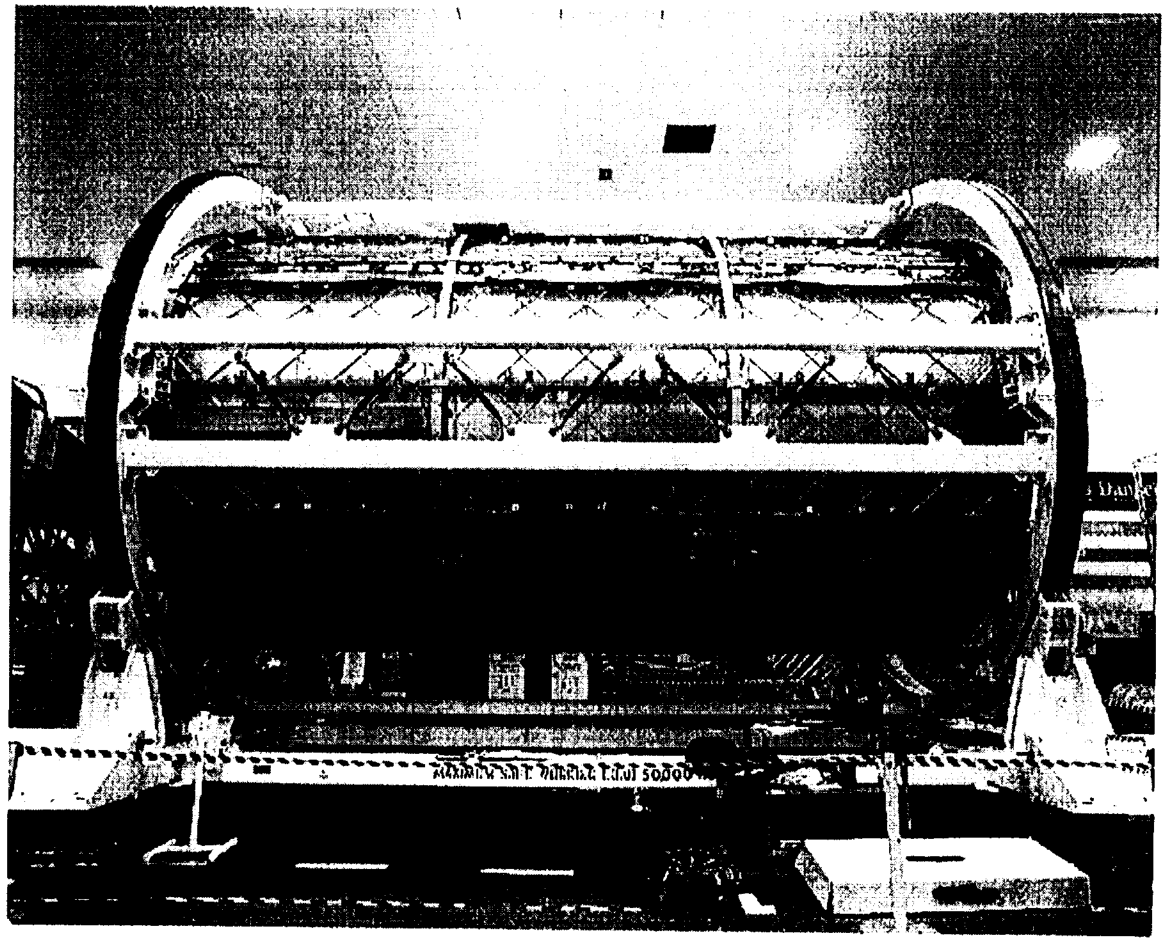
1 ... 1X-S6-RPa-M
2 ... 1Y-S6-RPa-M
3 ... 1Z-S6-RPa-M
4 ... 2X-S6-LPa-M
5 ... 2Y-S6-LPa-M
6 ... 2Z-S6-LPa-M
7 ... 3X-S5-RPa-M
8 ... 3Y-S5-RPa-M
9 ... 3Z-S5-RPa-M
10 .. 4X-S5-LPo-M
11 .. 4Y-S5-LPa-M
12 .. 4Z-S5-LPo-M
13 .. 5X-X2SO-S6/S5
14 .. 5R-X2SO-S6/S5
15 .. 6R-X2SO-S5/S4
16 .. 7R-X2SO-S4/S3
17br. 8R-X1Lb-S6/S5
17ar. 15R-X3Lb-F6/F5
18br. 9R-X2Lt-S6/S5
18ar. 16R-X2Lb-F6/F5
19 .. 10X-X1SO-S6/S5
20 .. 10R-X1SO-S6/S5
21 .. 11R-X1SO-S5/S4
22 .. 12R-X3SO-F6/P5
23 .. 13R-X2SO-S2/S1
24 .. 14Z-F6-LPo-M



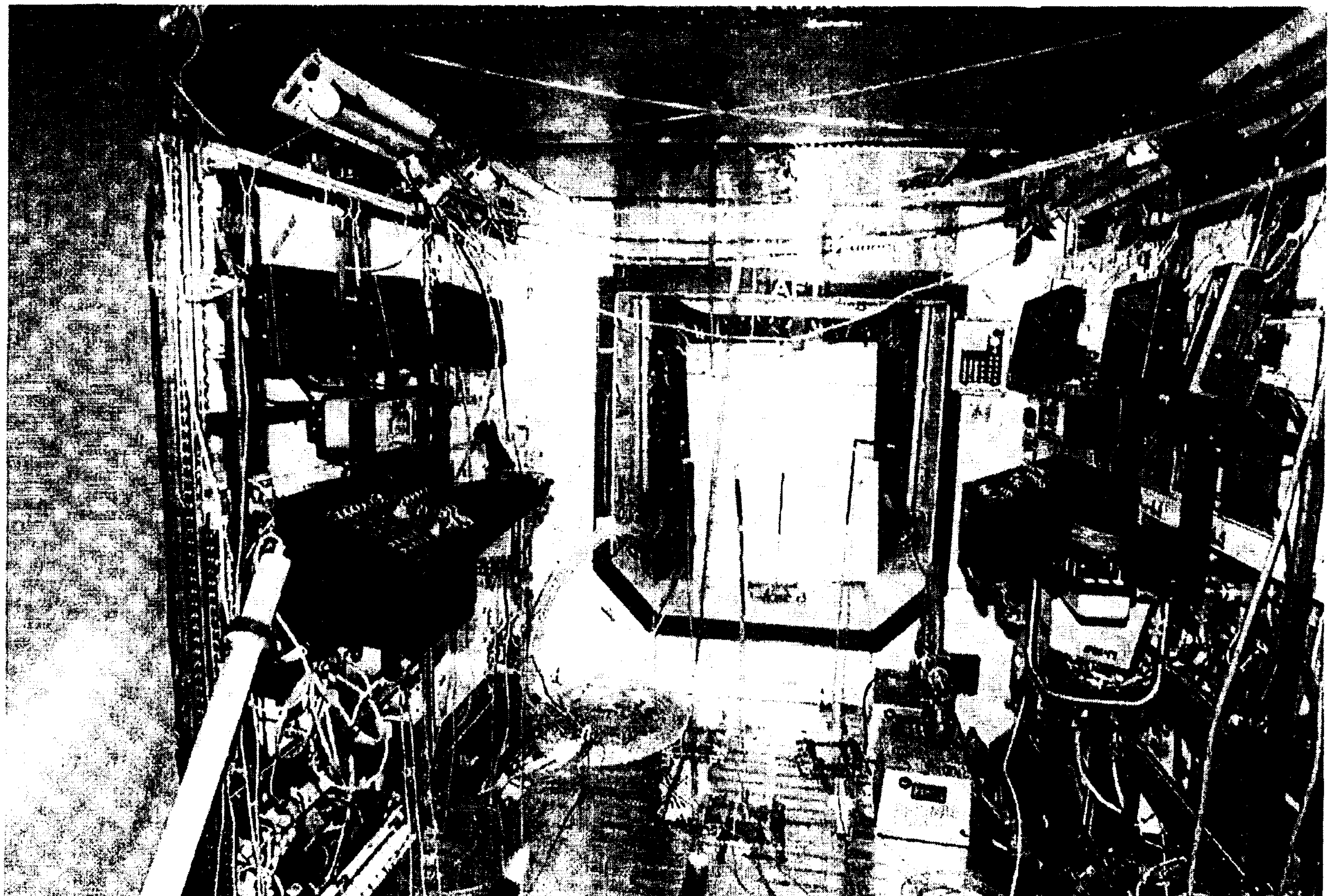


11-13 July 2000 **19th Microgravity Measurements Group Meeting** Crenwelge/O'Keefe/Miller/Sun/Snatcher

US Lab

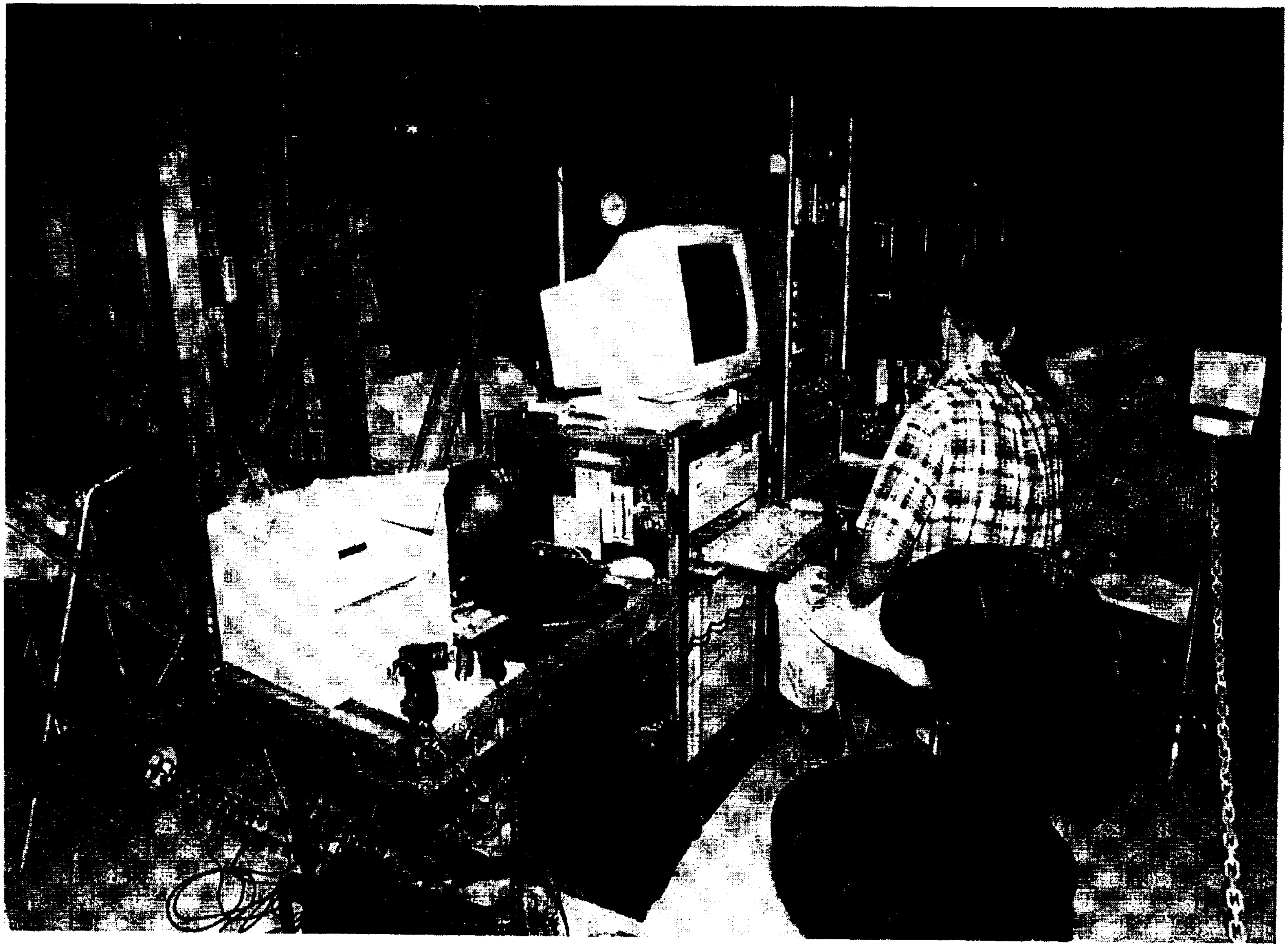


US Lab Interior Test Equipment



11-13 July 2000 | 19th Microgravity Measurements Group Meeting | Crenwelge/O'Keefe/Miller/Sun/Shekher

US Lab Exterior Test Equipment



DATA ANALYSIS PROCEDURES

1. Quick-look analyses were performed on the SSPF floor during test runs. Detailed data analyses are being performed post-test in Seattle, Houston and Huntsville.

2. Accelerometer, microphone, and force signals from the intermittent equipment operating tests, the acoustic reverberation tests, and the impulse hammer tests are being FFT analyzed over the 0-400 Hz frequency range in narrowband energy spectral density (ESD) format, triggering from impulse initiation, using force and exponential windowing (if needed), a time record length sufficient for the signals to decay to their respective background noise levels before record end, and multiple averages (when available). One-third octave band peak spectra are being computed from the narrowband data.

3. Accelerometer, microphone, and force signals from the continuous equipment operating tests, the sound source excitation tests, the shaker excitation tests, and the calibration, background, and baseline tests are being FFT analyzed over the 0-400 Hz frequency range in narrowband power spectral density (PSD) format, using the Hanning window and multiple averages. One-third octave band rms spectra are being computed from the narrowband data.

4. Acoustical power-to-sound pressure and acoustical power-to-structural acceleration transfer functions will be computed from the narrowband PSDs and 1/3-OB spectra of the acoustic source excitation tests.

5. Mechanical force-to-structural acceleration transfer functions have been computed from the narrowband ESDs and PSDs and the 1/3-OB spectra of the hammer impulse tests and the shaker excitation tests.

6. The effective acoustical power PSD of USL operating equipment systems is will be determined by first computing the sound pressure PSD ratio between USL equipment operating and the acoustic source operating and then multiplying this ratio by the known acoustic source sound power PSD.

7. The acoustically induced acceleration PSD due to operating USL equipment will be determined by multiplying the computed acoustical power PSD of step 6 by the square of the acoustical power-to-acceleration transfer functions of step 4.

8. The mechanically induced acceleration PSD due to operating USL equipment will be determined by subtracting the acoustically induced acceleration PSD of step 7 from the measured total acceleration PSD of step 3.

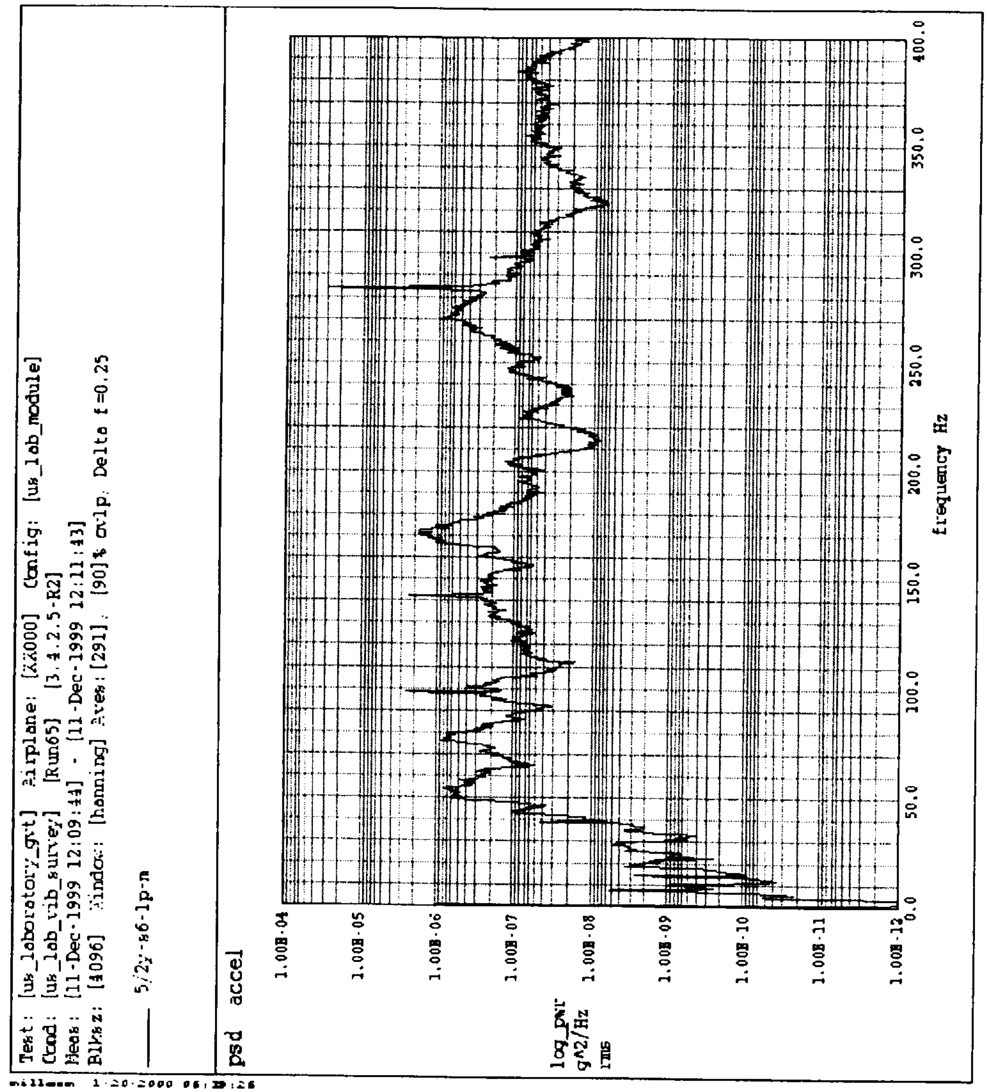
9. In cases where either measured or analytical mechanical force-to-structural acceleration transfer functions exist, the effective mechanical force PSD matrix of USL operating equipment may be computed by deconvolving the square of the force-to-acceleration transfer function matrix from the mechanically induced acceleration PSD matrix of 8.

Data Reduction Requirements

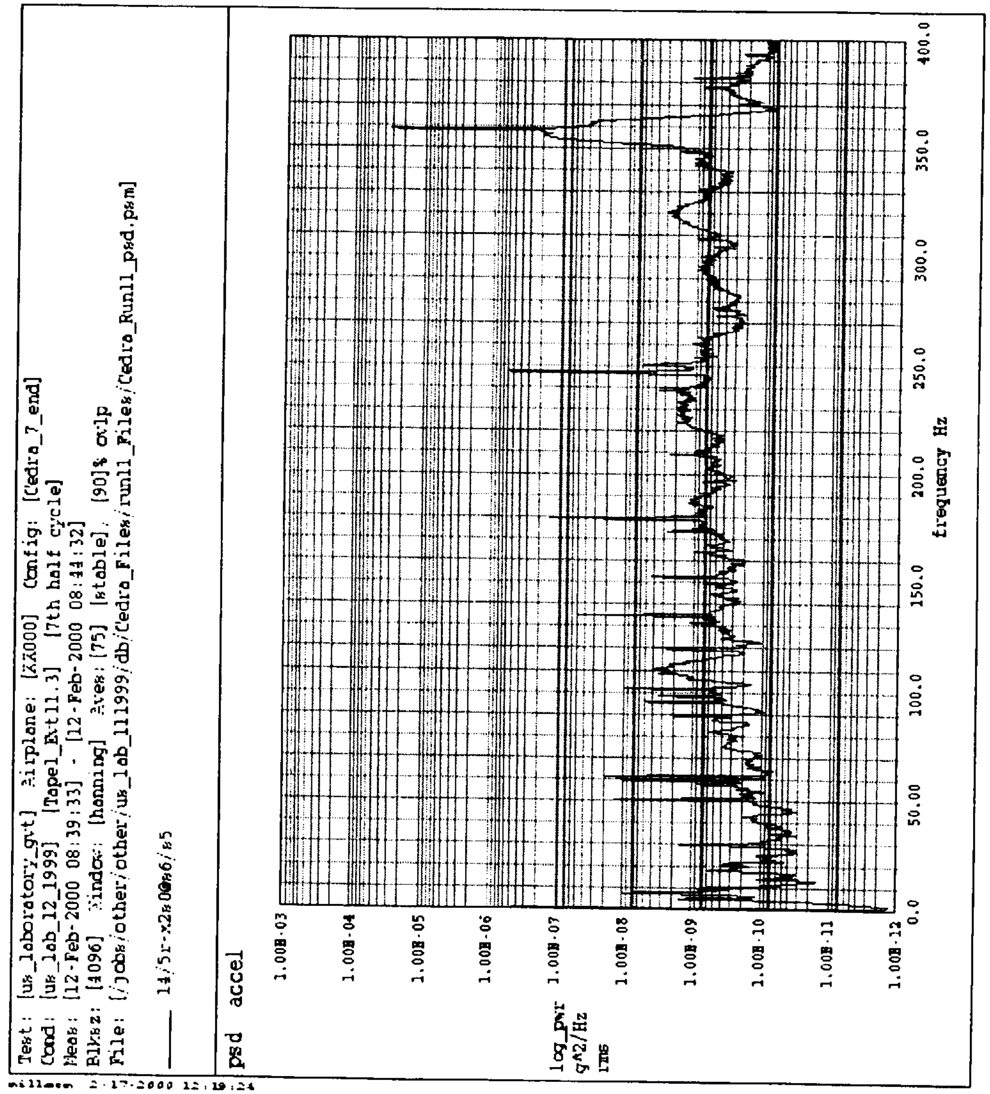
Test Type	Accel vs Time, g	Force vs Time, lb	Sound Press vs Time, SPR	Accel ESD, $(g/Hz)^2$	Force ESD, $(Lb/Hz)^2$	Sound Press ESD, $(SPR/Hz)^2$	Accel PSD, g^2/Hz	Force PSD, lb^2/Hz	Sound Press PSD, SPR^2/Hz	A / F FRF, g/lb	A / SW FRF, $g/W^{1/2}$	SP / SW FRF, $Pa/W^{1/2}$	F-A Coh	SP-A Coh
Background							R		R					
Baseline							R		R					
Continuous USL Equipment							R		R					
Continuous Sound Source							R		R		R	R		R
Continuous Vibrator Source							R	R		R			R	
Intermittent USL Equipment	R		R	R		R								
Hammer Impulse Source	R	R		R	R					R			R	

1. R denotes a required item
2. Physical quantity abbreviations, symbols, and units used in the tables are: acceleration (Accel, A, g), sound pressure ratio (Sound Press, SP, SPR), sound power (SW, W), and force (F, lb).
3. Data reduction quantity abbreviations used in the tables are power spectral density (PSD), energy spectral density (ESD), frequency response function (FRF), and coherence (Coh).
4. The microphone of the calibrated sound power source (B&K 4205) was calibrated in the test to the same level as the 8 interior microphones. Using the meter of the signal generator for the sound power source, the test sound power was set at the calibrated sound power level in dB (re 1 pW). To calibrate the sound power induced FRFs (A/SW and SP/SW), the sound pressure ratio (SPR) of the source reference microphone must be scaled to the correct sound power (W).

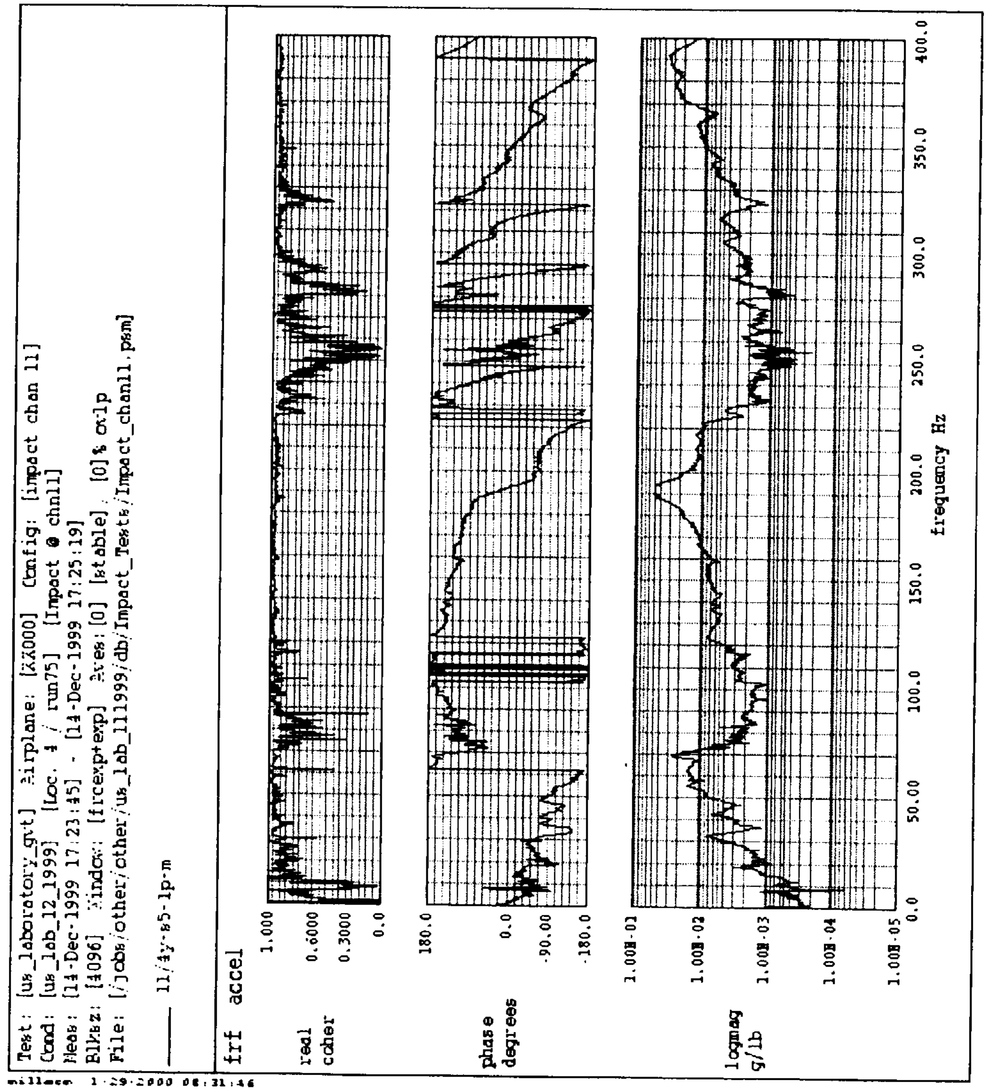
Typical All Source (except CDRA) Induced PSD



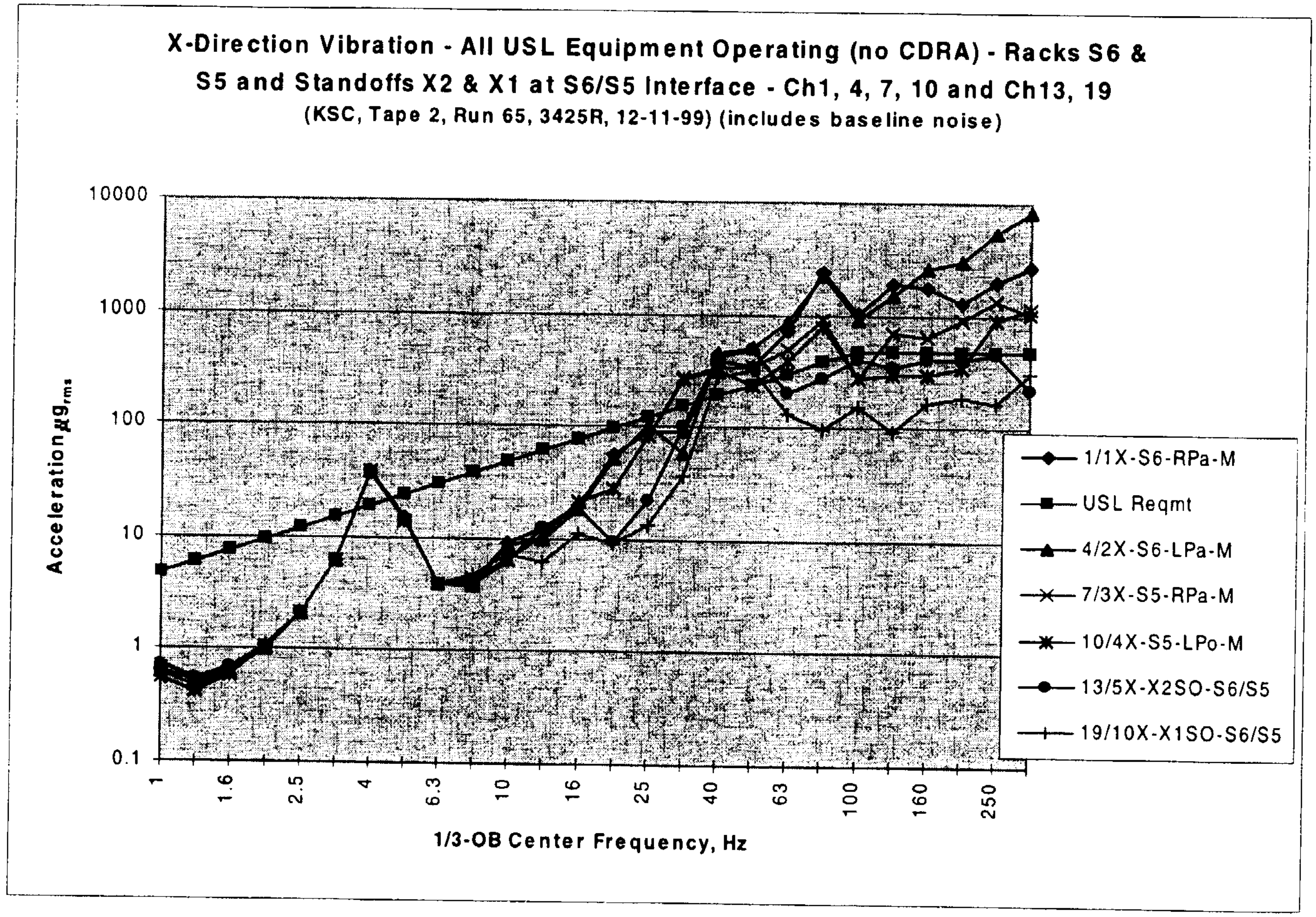
Typical CDRA Induced Acceleration PSD



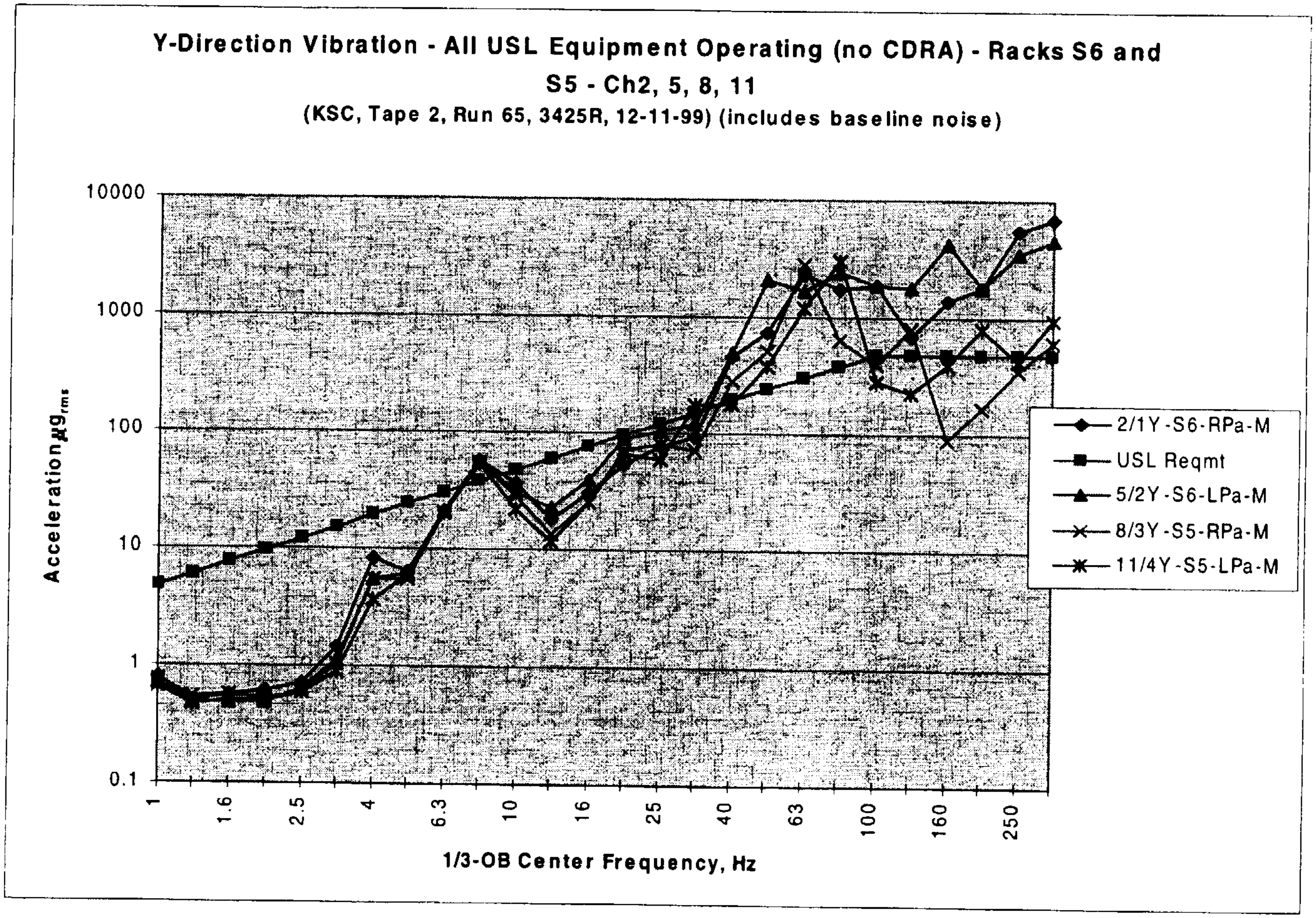
Typical Impulse Hammer Induced Transfer Function



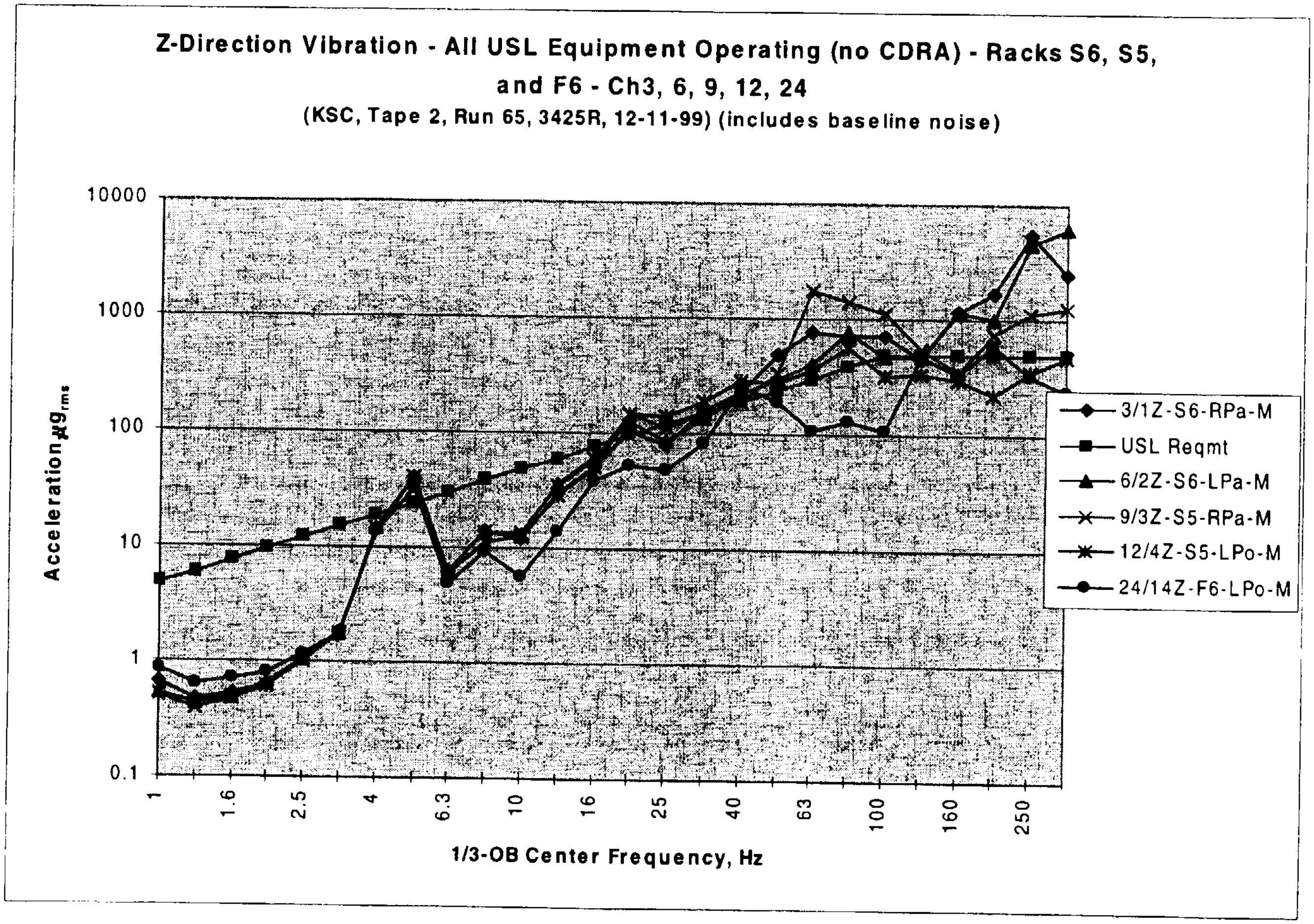
X-Direction Vibration - All USL Equipment Operating (no CDRA) - Racks S6 & S5 and Standoffs X2 & X1 at S6/S5 Interface



Y-Direction Vibration - All USL Equipment Operating (no CDRA) - Racks S6 and S5

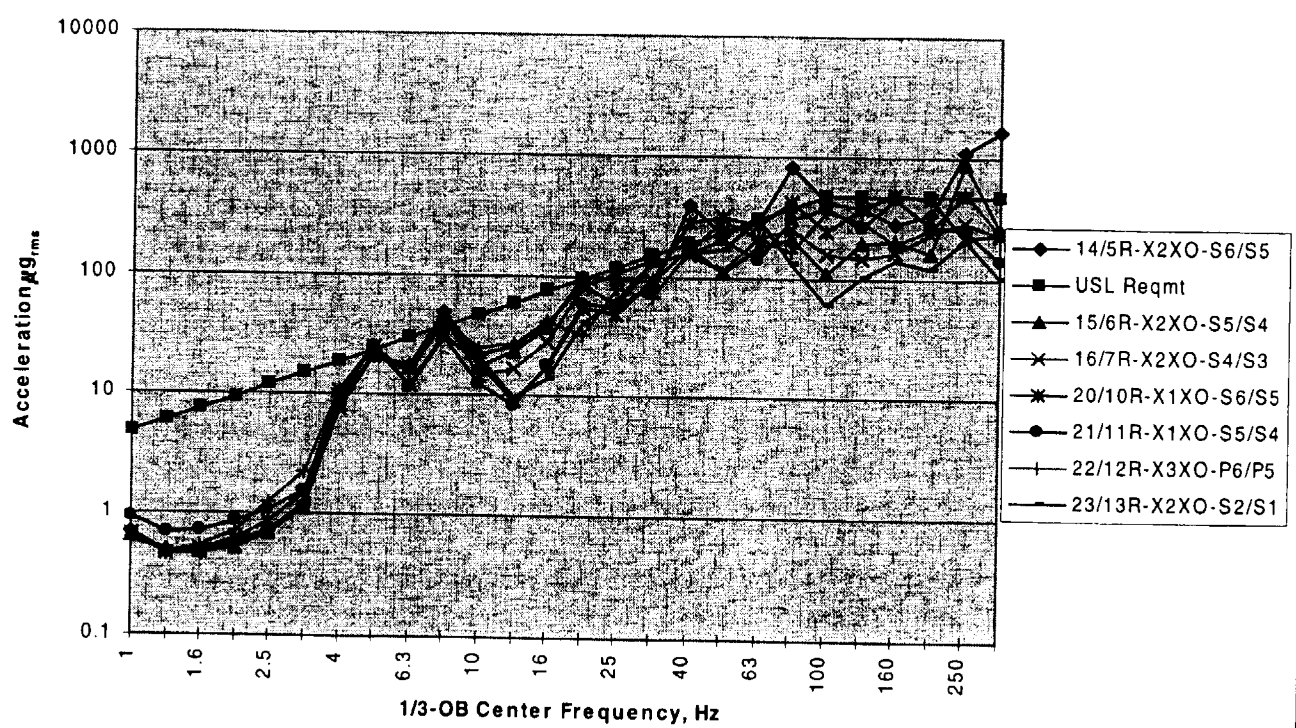


Z-Direction Vibration - All USL Equipment Operating (no CDRA) - Racks S6, S5, and F6

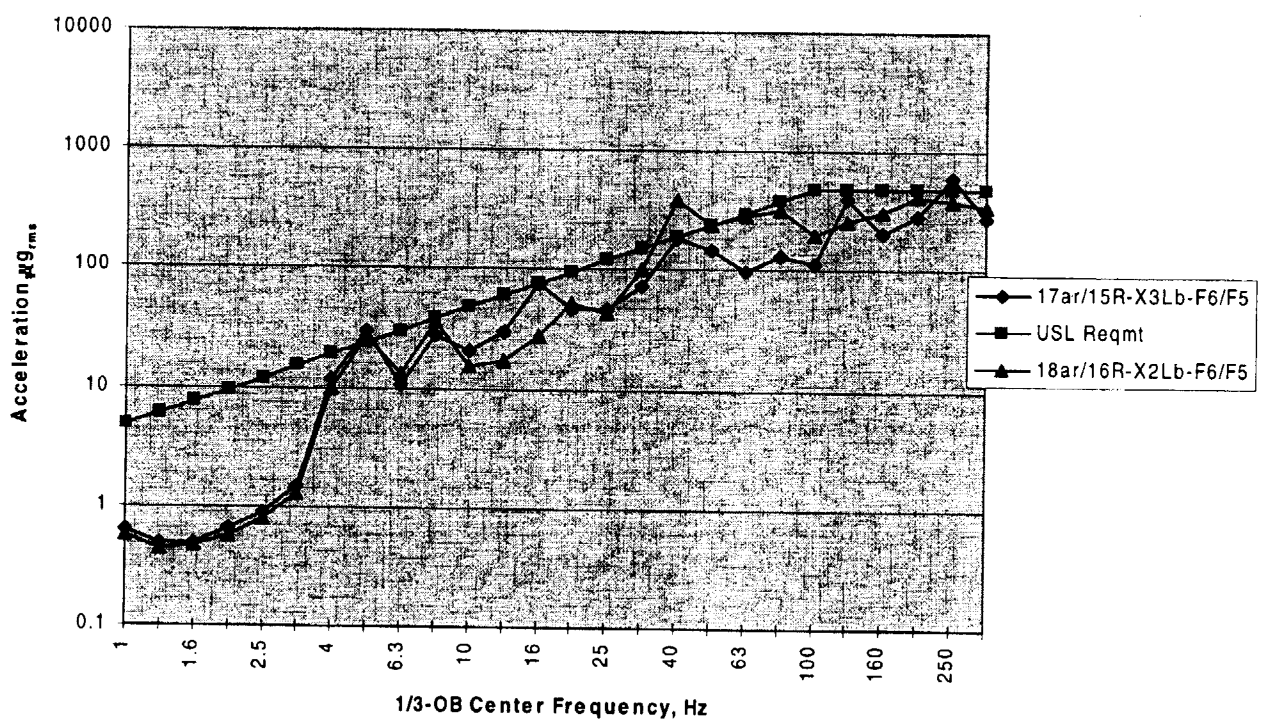


R-Direction Vibration - All USL Equipment Operating (no CDRA) - Standoffs X1, X2, & X3 at Rack Interfaces 6/5, 5/4, 4/3, & 2/1

R-Direction Vibration - All USL Equipment Operating (no CDRA) - Standoffs X1, X2, & X3 at Rack Interfaces 6/5, 5/4, 4/3, & 2/1 - Ch14, 15, 16, 20, 21, 22, 23
(KSC, Tape 2, Run 65, 3425R, 12-11-99) (includes baseline noise)

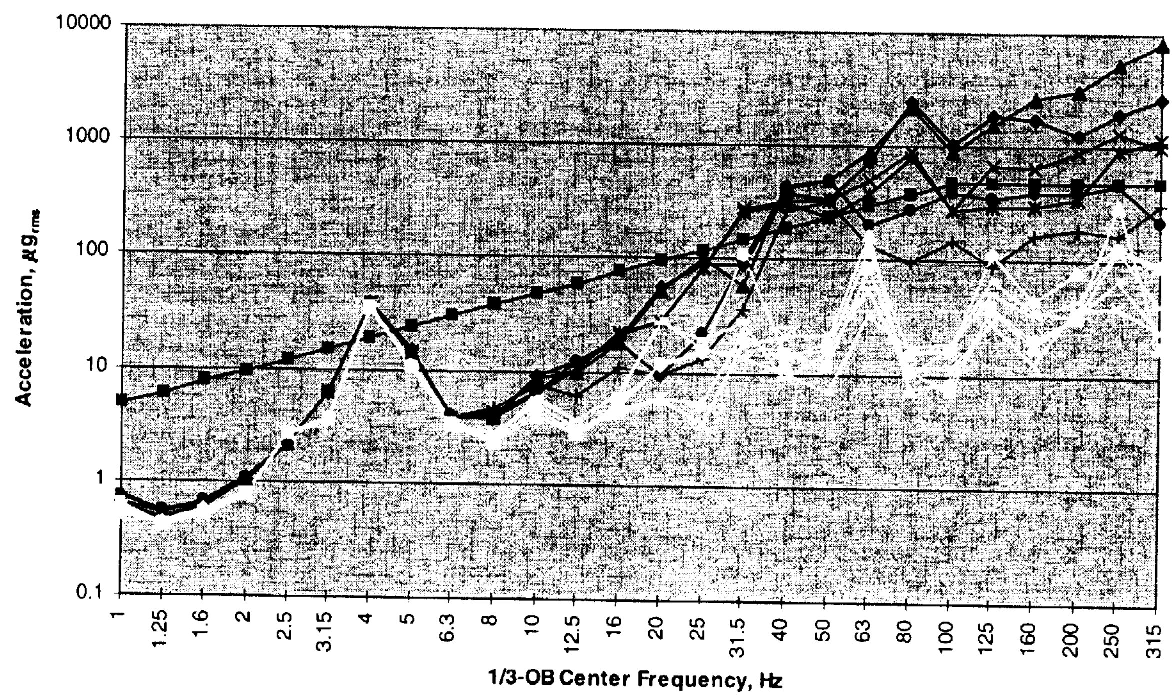


R-Direction Vibration - All USL Equipment Operating (no CDRA) - Longerons X3Lb and X2Lb



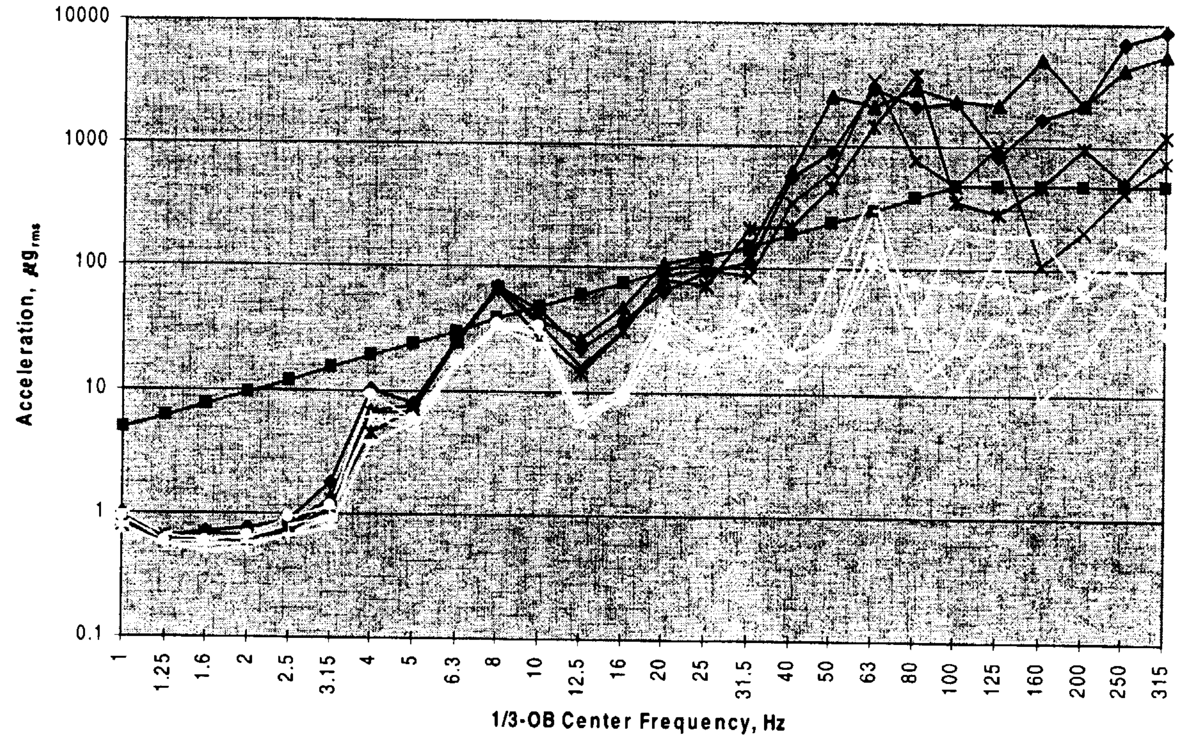
Comparison of Operating and Baseline Data for X-Direction

Figure 2. X-Direction Vibration - All USL Equipment Operating (no CDRA) (dark lines) vs Baseline (light lines) - Racks S6 & S5 and Standoffs X2 & X1 at S6/S5 Interface - Ch1, 4, 7, 10 and Ch13, 19
(KSC, Tape 2, Run 65, 3425R, 12-11-99)



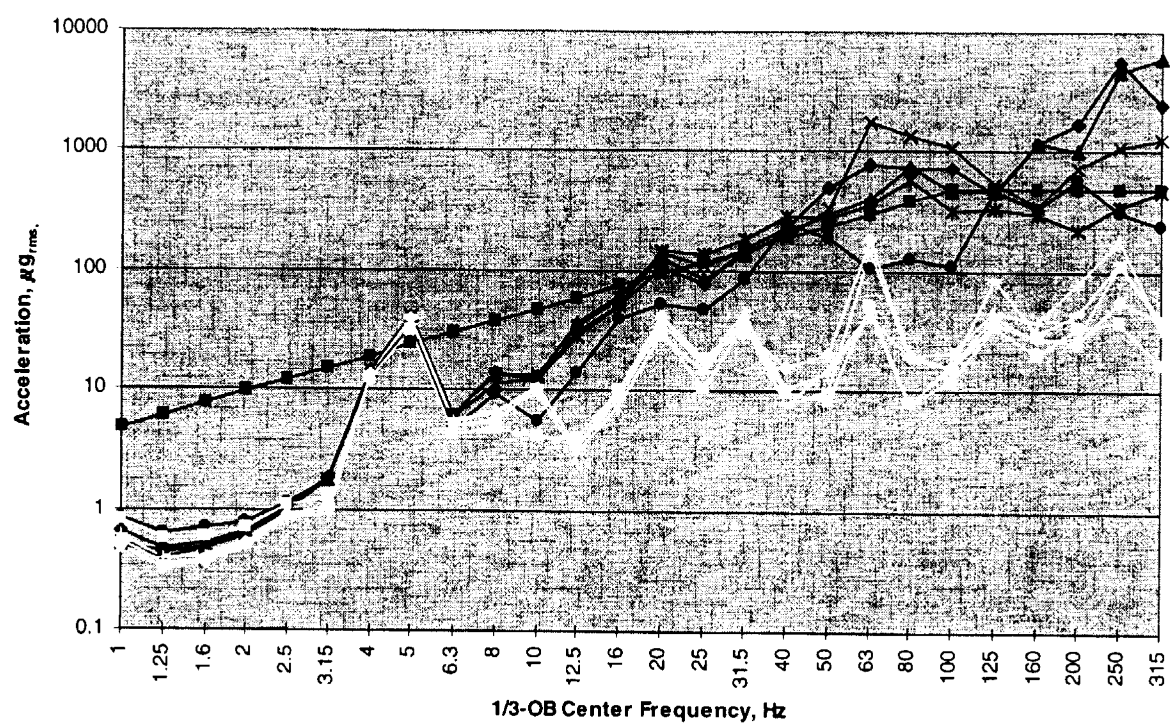
Comparison of Operating and Baseline Data for Y-Direction

Figure 3. Y-Direction Vibration - All USL Equipment Operating (no CDRA) (dark lines) vs Baseline (light lines) - Racks S6 and S5 - Ch2, 5, 8, 11
(KSC, Tape 2, Run 65, 3425R, 12-11-99)



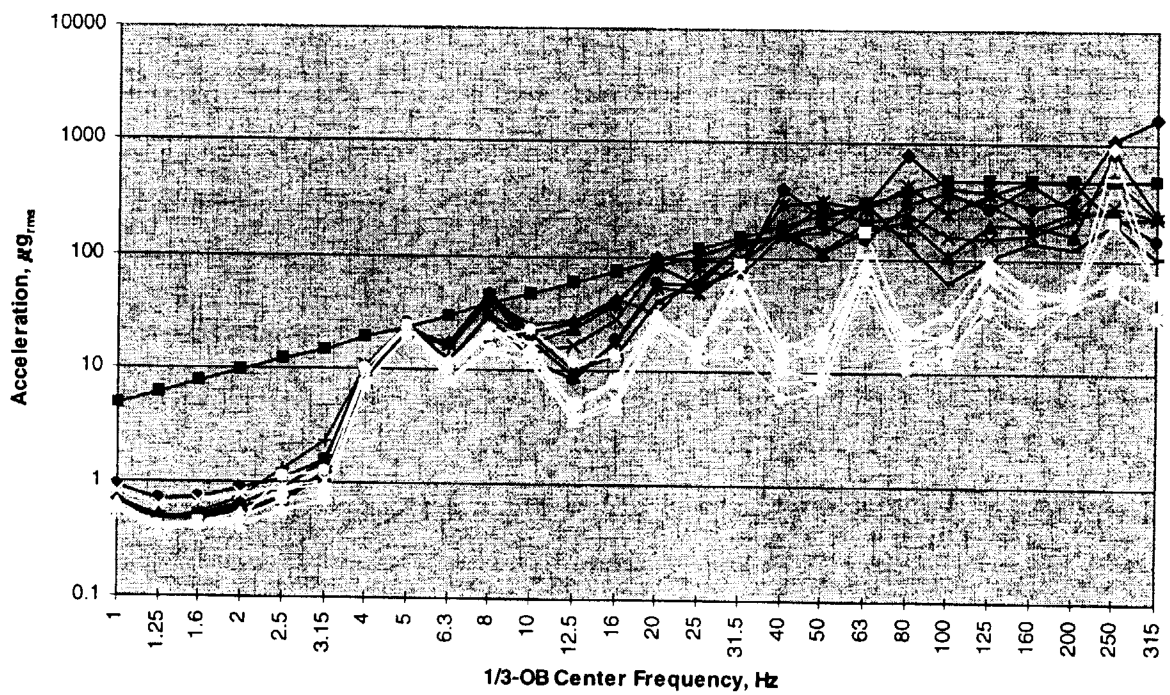
Comparison of Operating and Baseline Data for Z-Direction

Figure 4. Z-Direction Vibration - All USL Equipment Operating (no CDRA) (dark lines) vs Baseline (light lines) - Racks S6, S5, and F6 - Ch3, 6, 9, 12, 24
(KSC, Tape 2, Run 65, 3425R, 12-11-99)



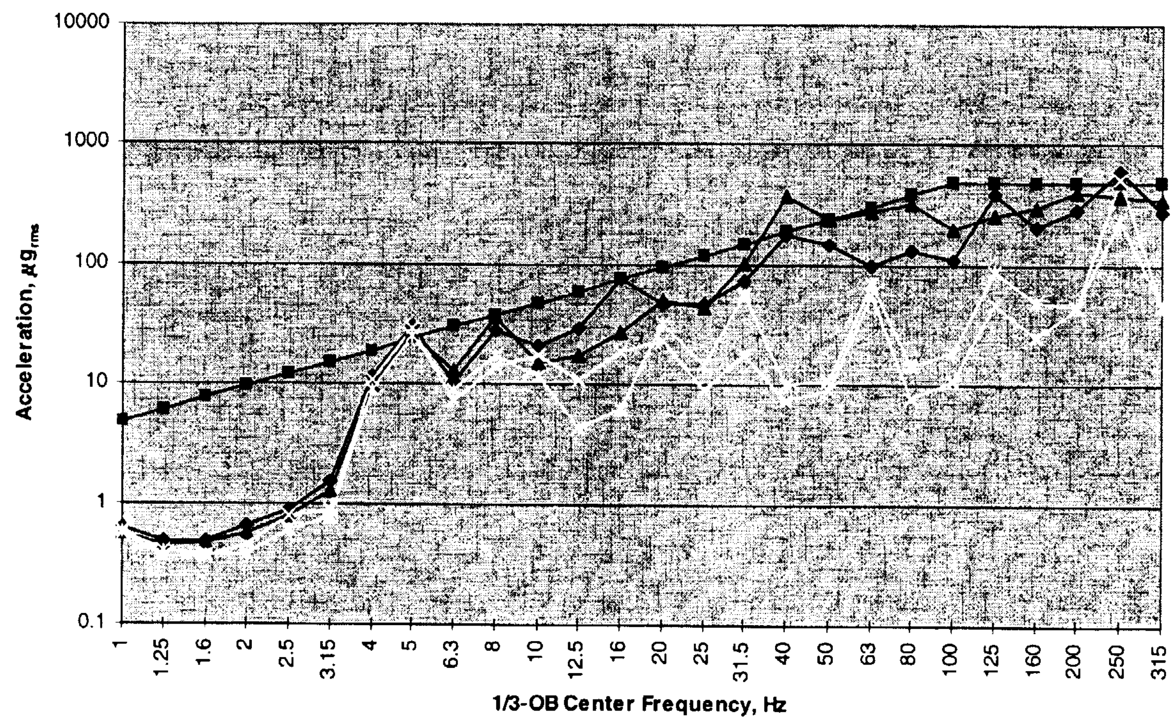
Comparison of Operating and Baseline Data for Standoffs (R-Direction)

Figure 5. R-Direction Vibration - All USL Equipment Operating (no CDRA) (dark lines) vs Baseline (light lines) - Standoffs X1, X2, & X3 at Rack Interfaces 6/5, 5/4, 4/3, & 2/1 - Ch14, 15, 16, 20, 21, 22, 23
(KSC, Tape 2, Run 65, 3425R, 12-11-99)

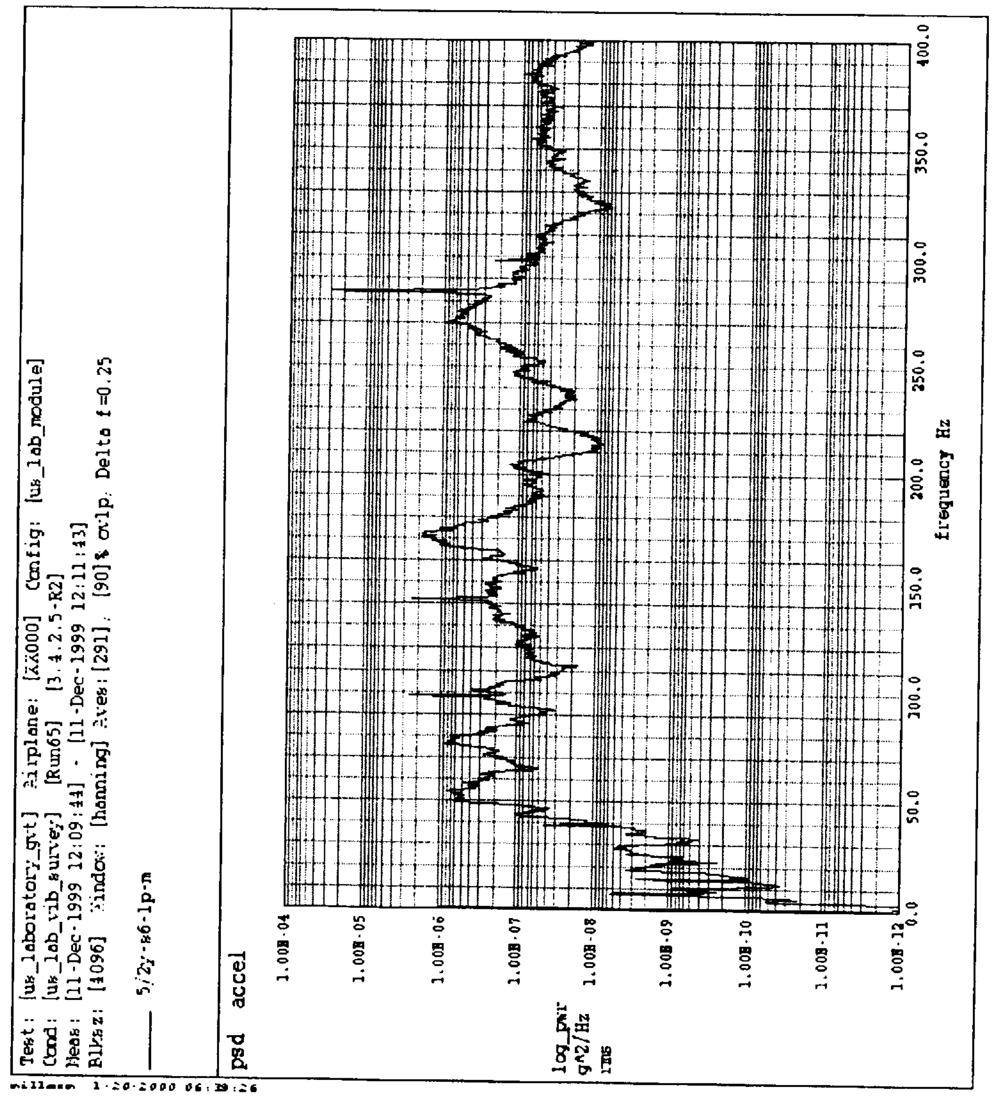


Comparison of Operating and Baseline Data for Longerons (R-Direction)

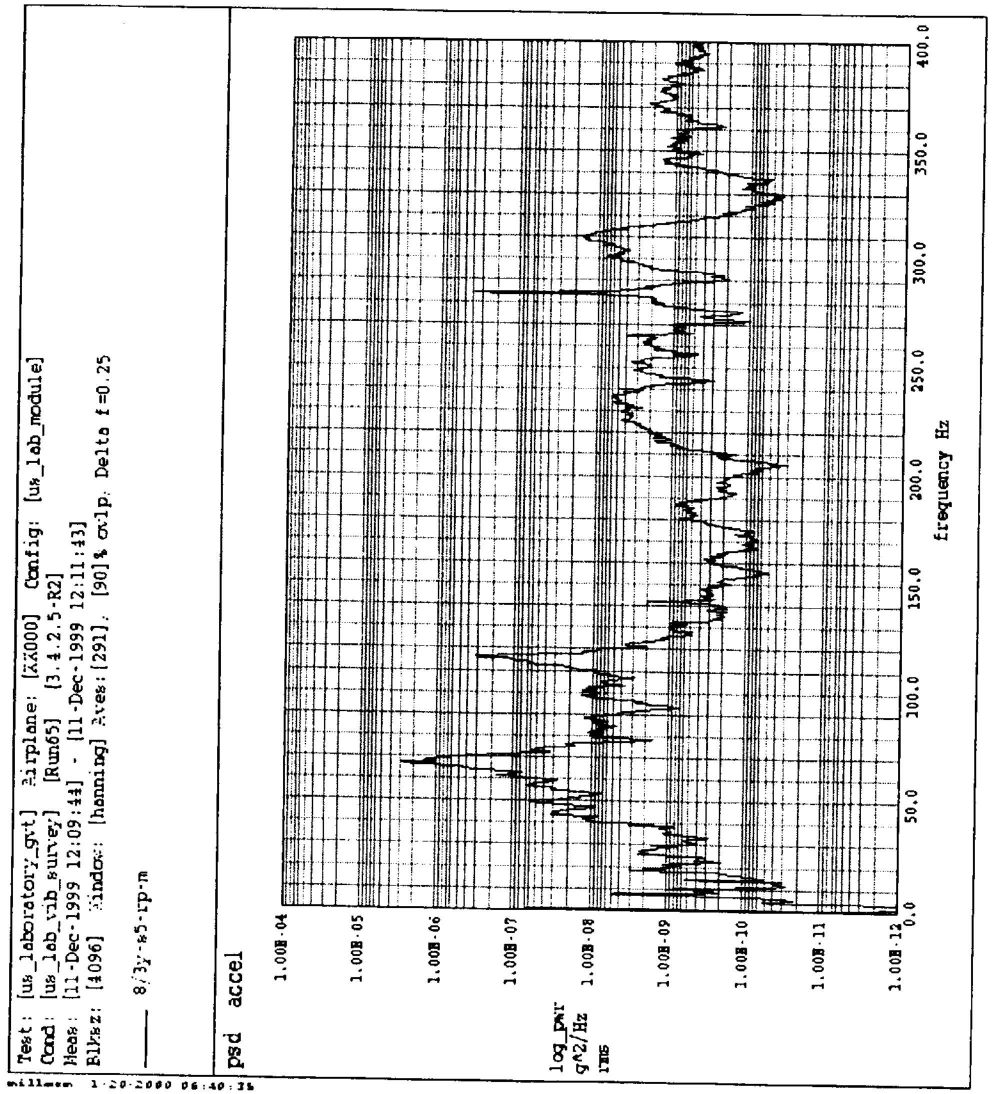
Figure 6. R-Direction Vibration - All USL Equipment Operating (no CDRA) (dark lines) vs Baseline (light lines) - Longerons X3Lb and X2Lb - Ch17ar, 18ar
(KSC, Tape 2, Run 65, 3425R, 12-11-99)



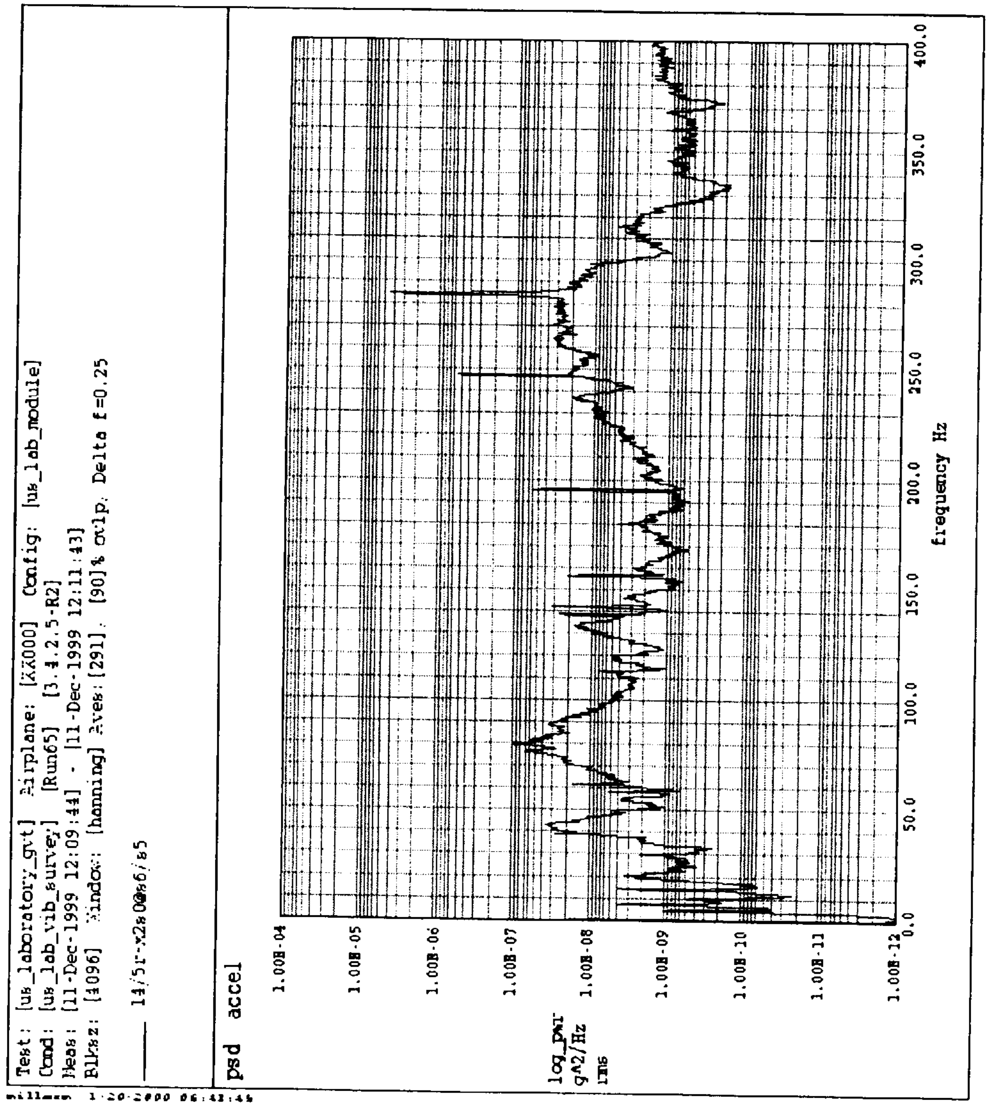
All Source (except CDRA) Induced Y-Direction Acceleration on S6



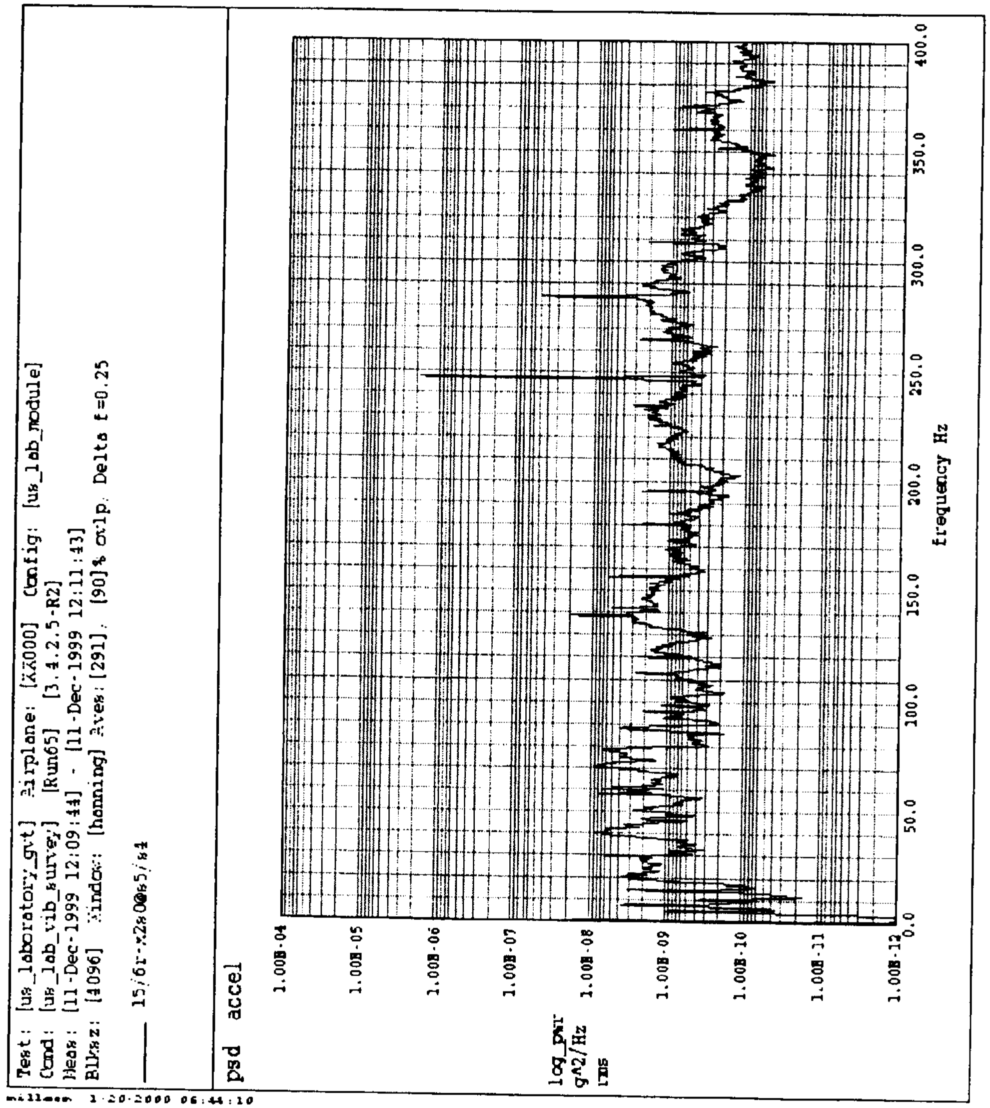
All Source (except CDRA) Induced Y-Direction Acceleration on S5



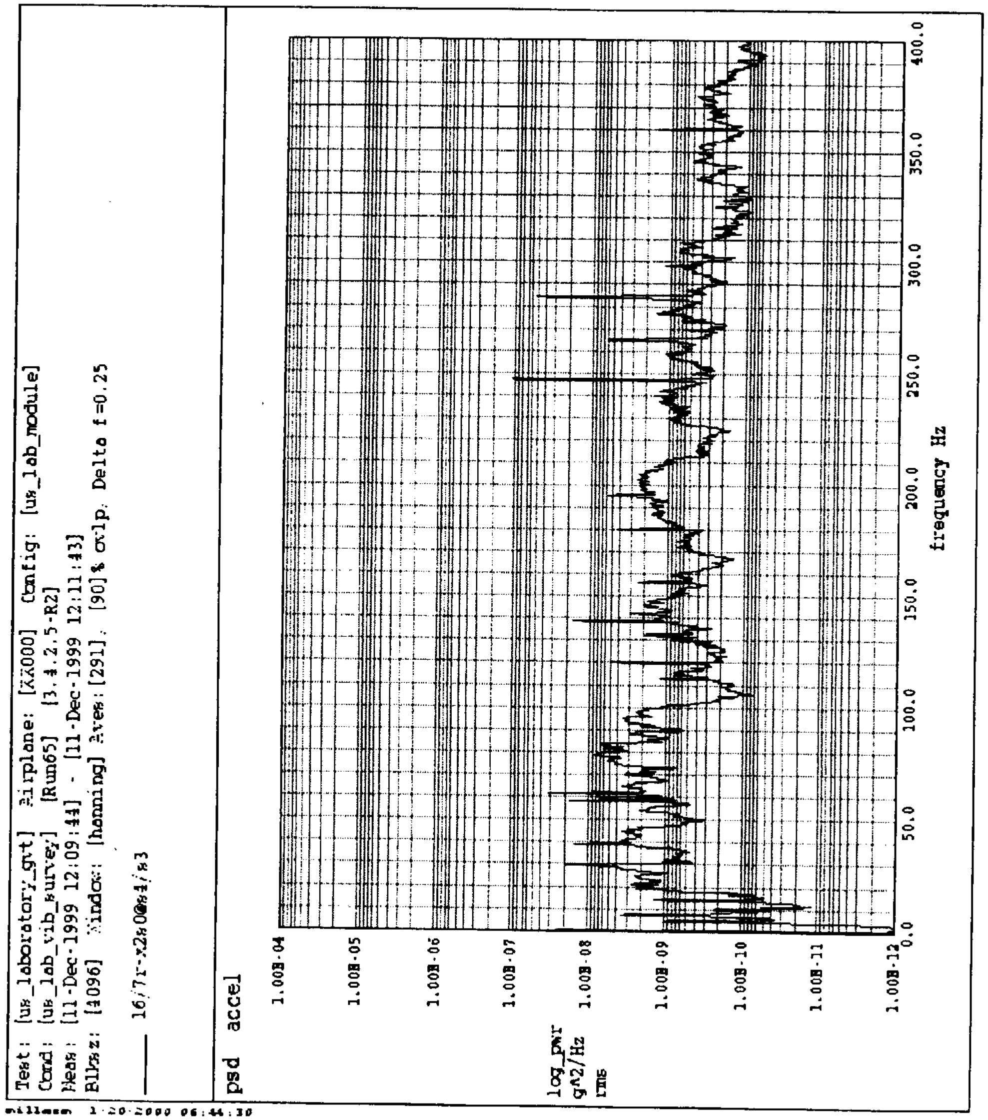
All Source (except CDRA) Induced R-Direction Acceleration on X2 at S6/S5 IF



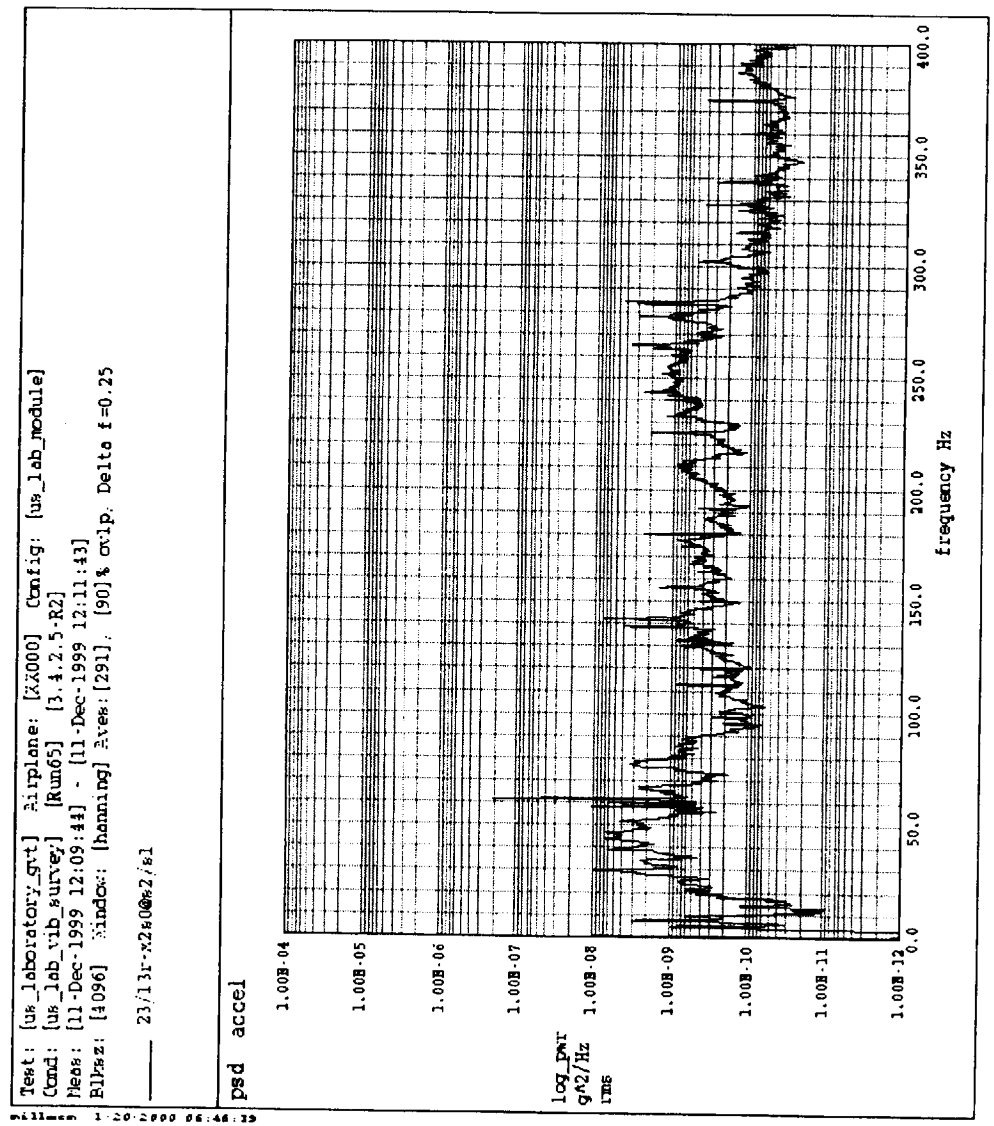
All Source (except CDRA) Induced R-Direction Acceleration on X2 at S5/S4 IF



All Source (except CDRA) Induced R-Direction Acceleration on X2 at S4/S3 IF



All Source (except CDRA) Induced R-Direction Acceleration on X2 at S2/S1 IF



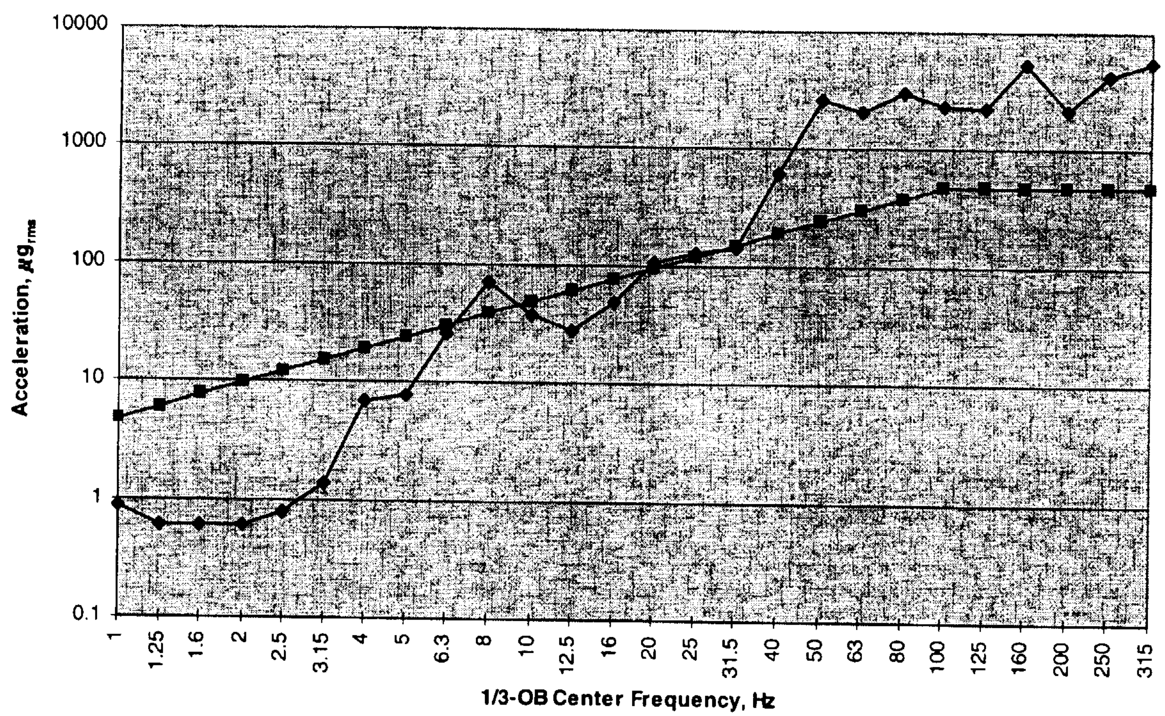
11-13 July 2000

19th Microgravity Measurements Group Meeting

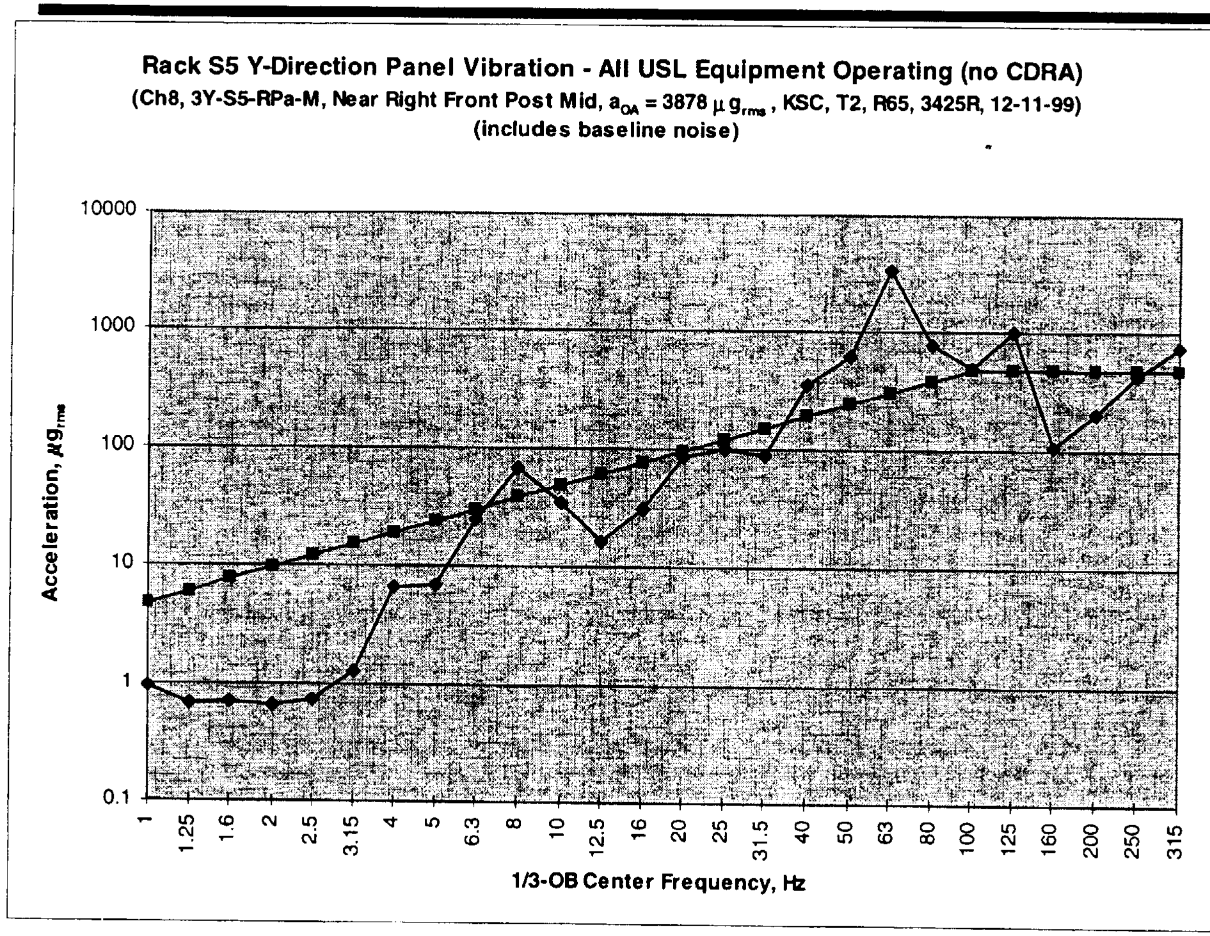
Crenwelge/O'Keefe/Miller/
Sun/Shekher

All Source (except CDRA) Induced Y-Direction Acceleration on S6

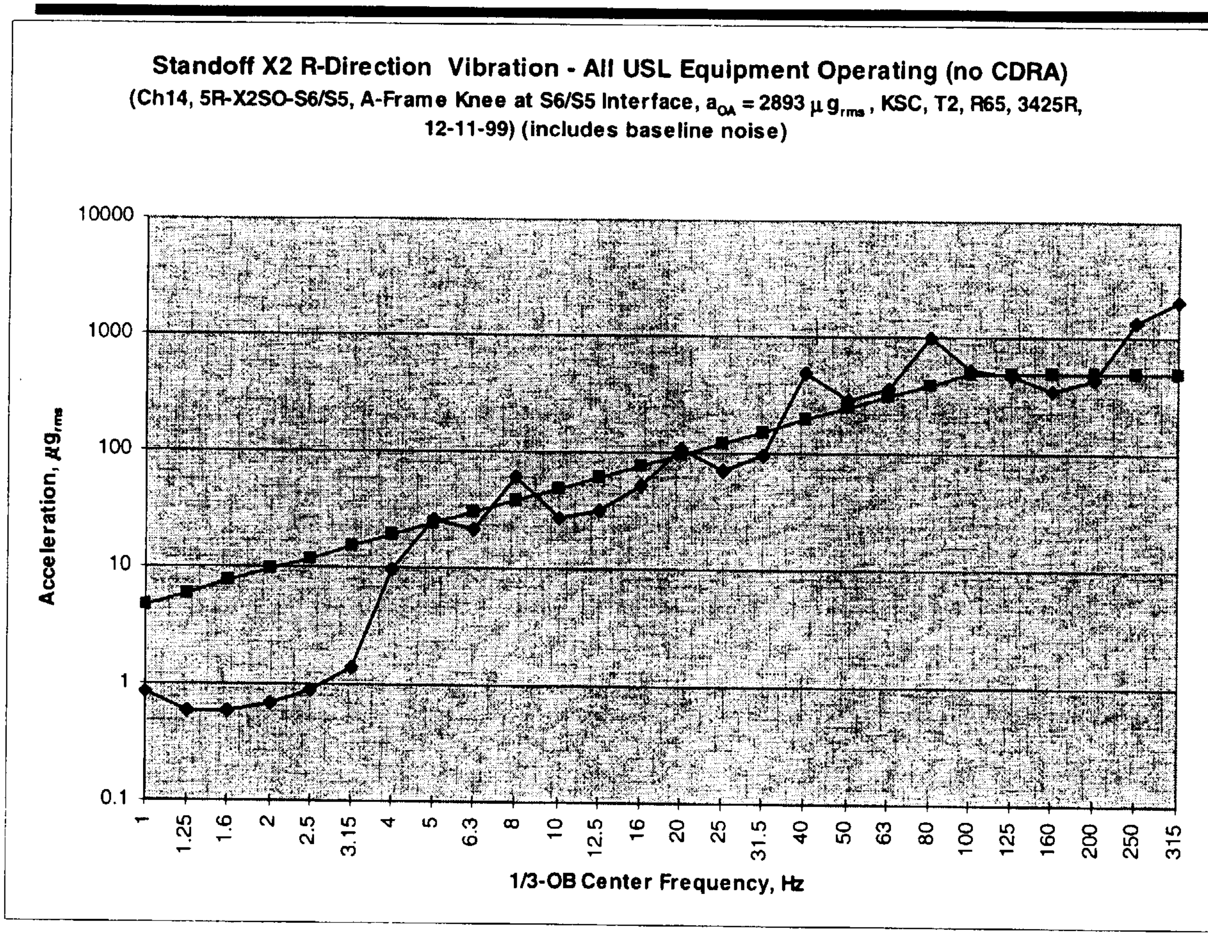
Rack S6 Y-Direction Panel Vibration - All USL Equipment Operating (no CDRA)
(Ch5, 2Y-S6-LPa-M, Near Left Front Post Mid, a_{OA} = 10763 μg_{rms}, KSC, T2, R65, 3425R, 12-11-99)
(includes baseline noise)



All Source (except CDRA) Induced Y-Direction Acceleration on S5

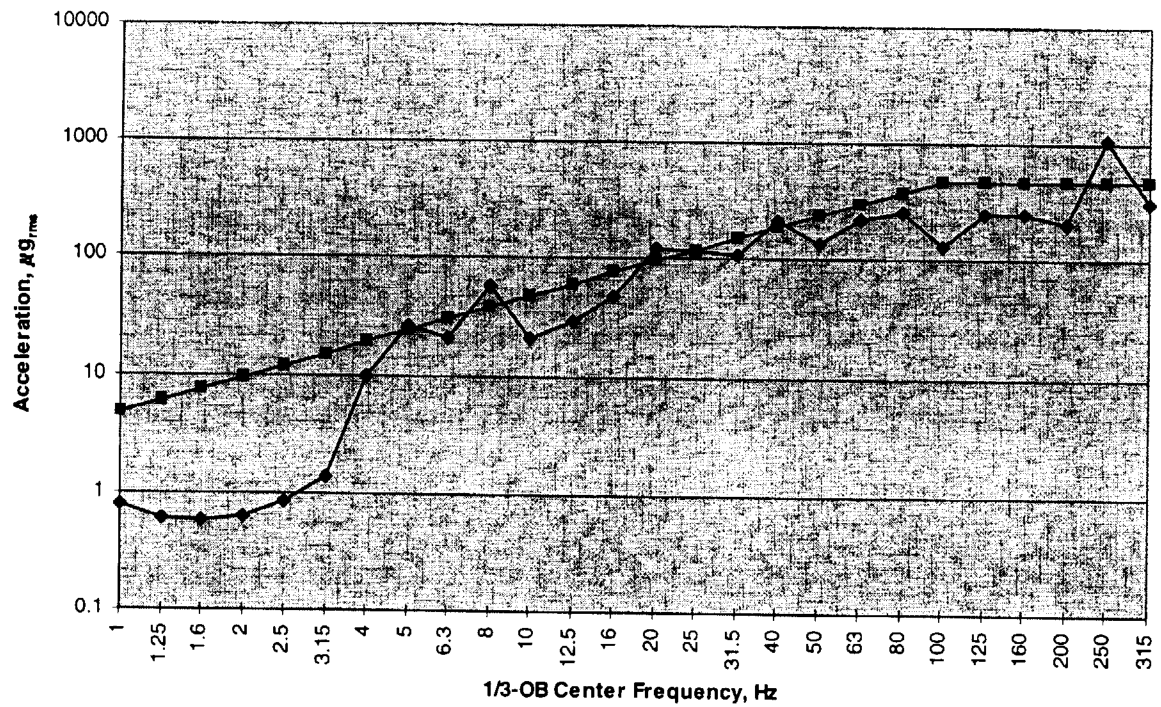


All Source (except CDRA) Induced R-Direction Acceleration on X2 at S6/S5 IF

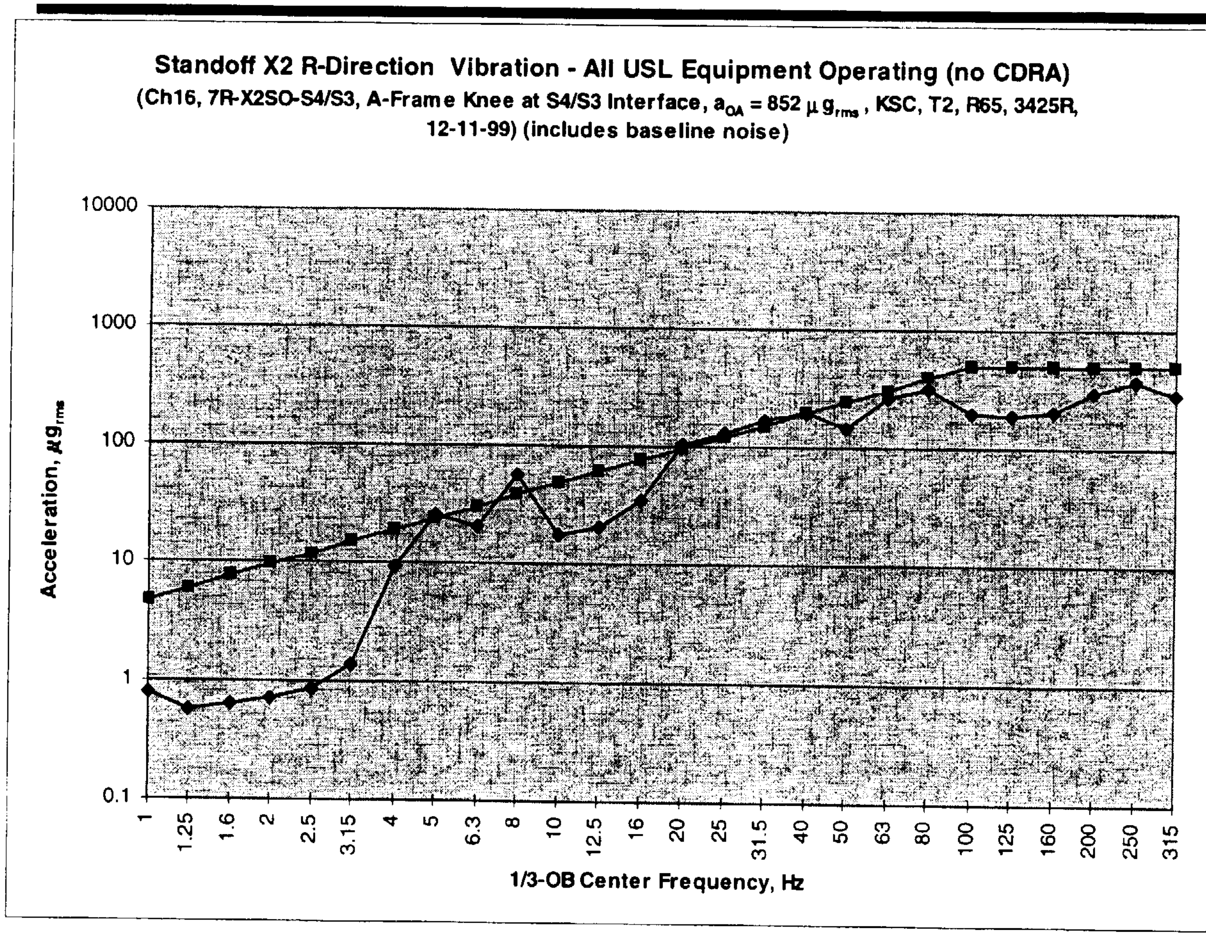


All Source (except CDRA) Induced R-Direction Acceleration on X2 at S5/S4 IF

Standoff X2 R-Direction Vibration - All USL Equipment Operating (no CDRA)
(Ch15, 6R-X2SO-S5/S4, A-Frame Knee at S5/S4 Interface, $a_{OA} = 1308\ \mu g_{rms}$, KSC, T2, R65, 3425R, 12-11-99) (includes baseline noise)

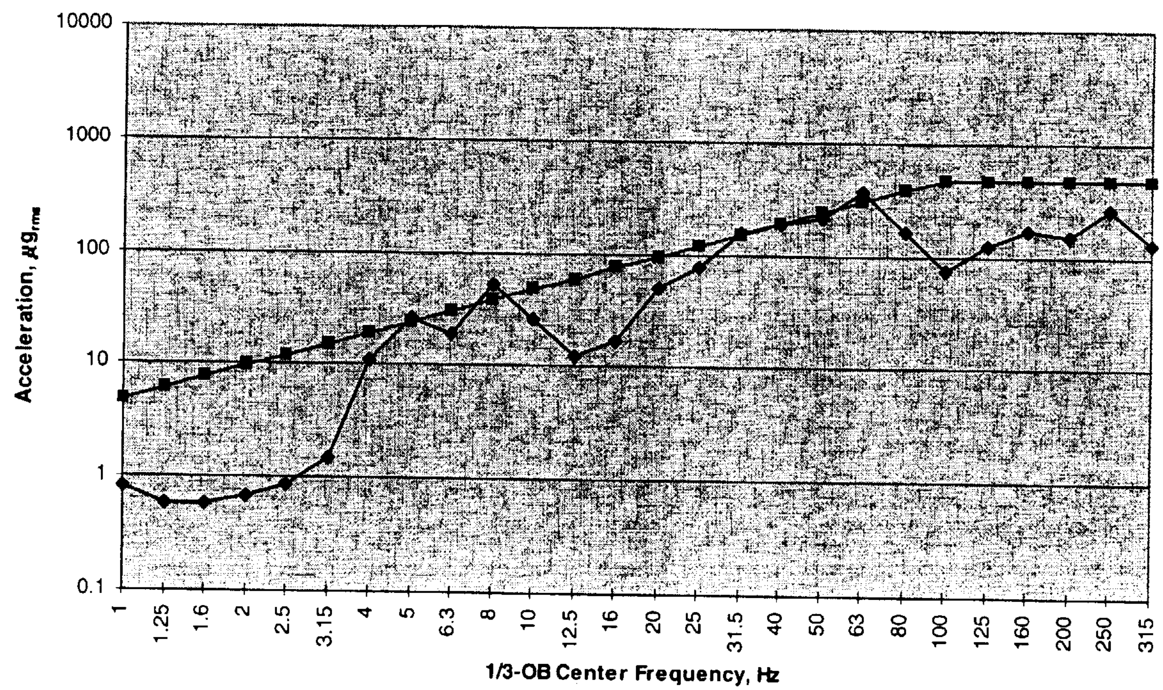


All Source (except CDRA) Induced R-Direction Acceleration on X2 at S4/S3 IF

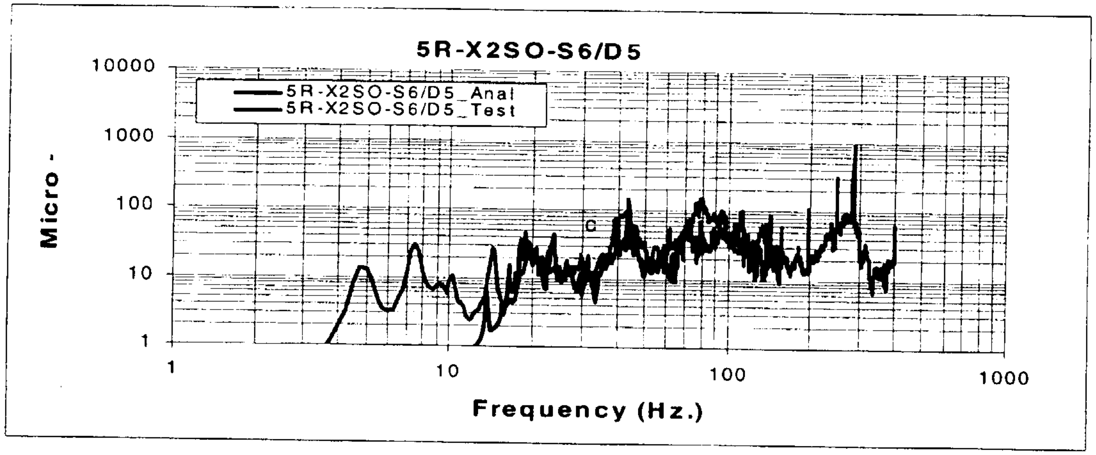


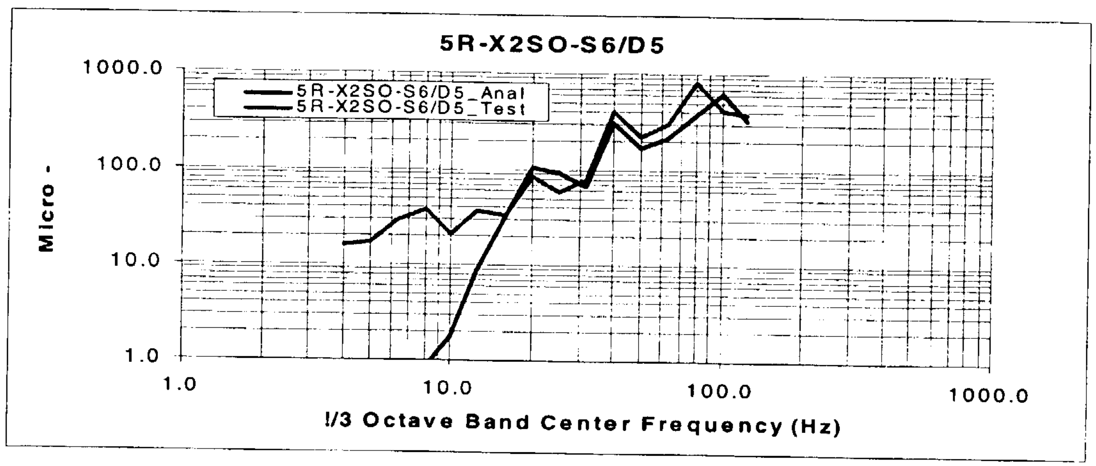
All Source (except CDRA) Induced R-Direction Acceleration on X2 at S2/S1 IF

Standoff X2 R-Direction Vibration - All USL Equipment Operating (no CDRA)
(Ch23, 13R-X2SO-S2/S1, A-Frame Knee at S2/S1 Interface, $a_{OA} = 681\ \mu g_{rms}$, KSC, T2, R65, 3425R, 12-11-99) (includes baseline noise)

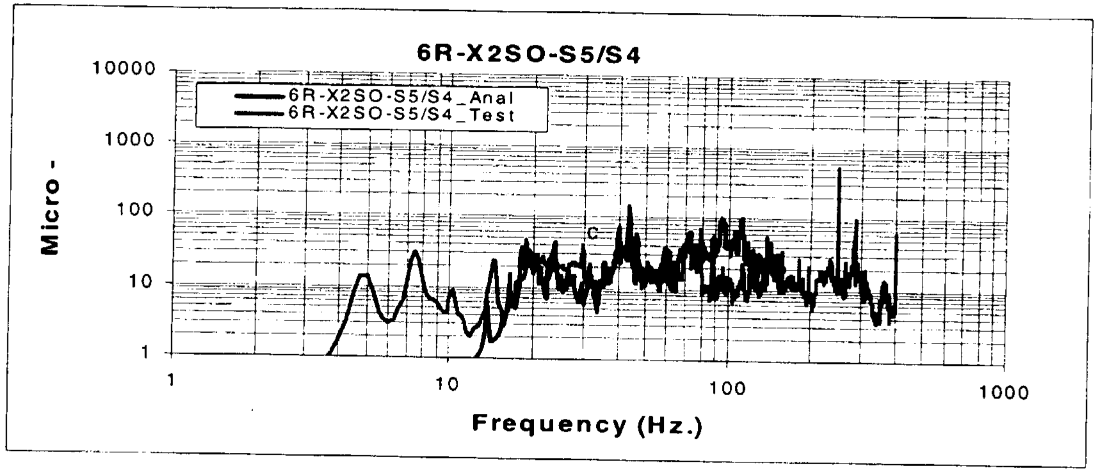


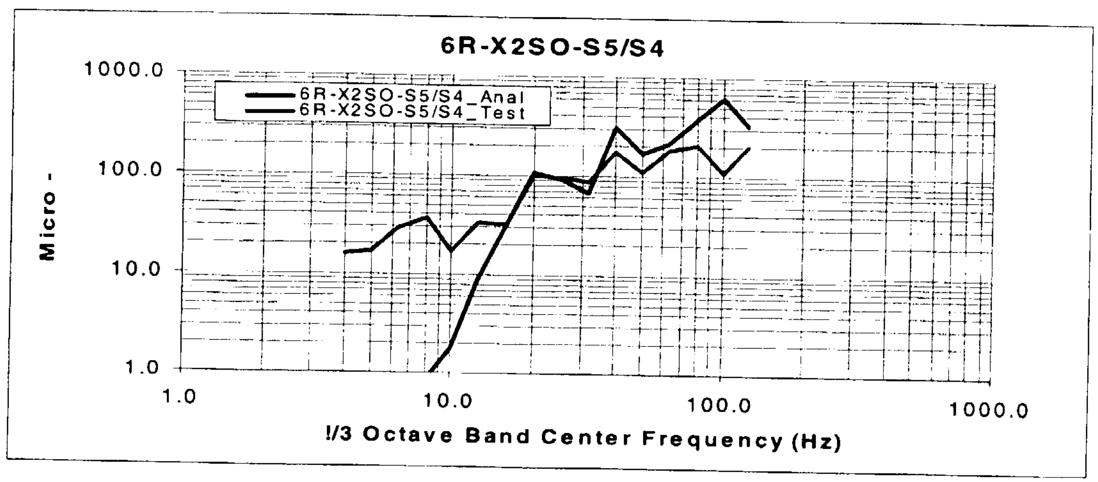
FEA Predicted vs Measured Response - X2 Standoff at S6/S5 IF



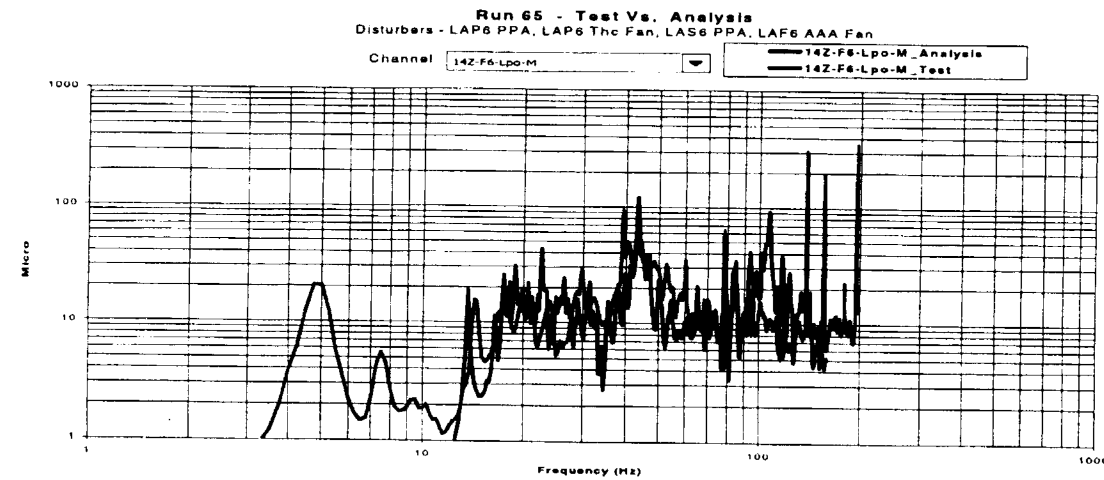


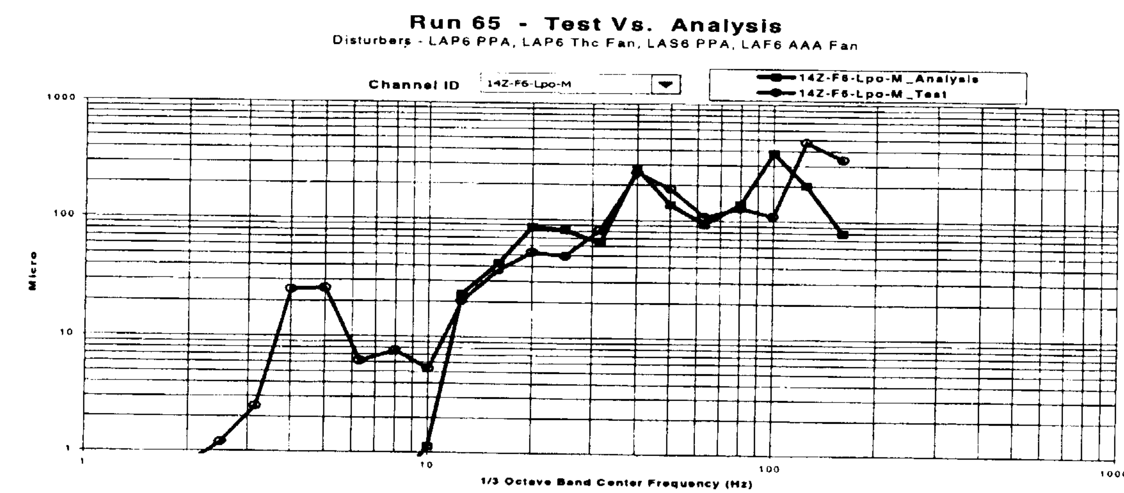
FEA Predicted vs Measured Response - X2 Standoff at S5/S4 IF



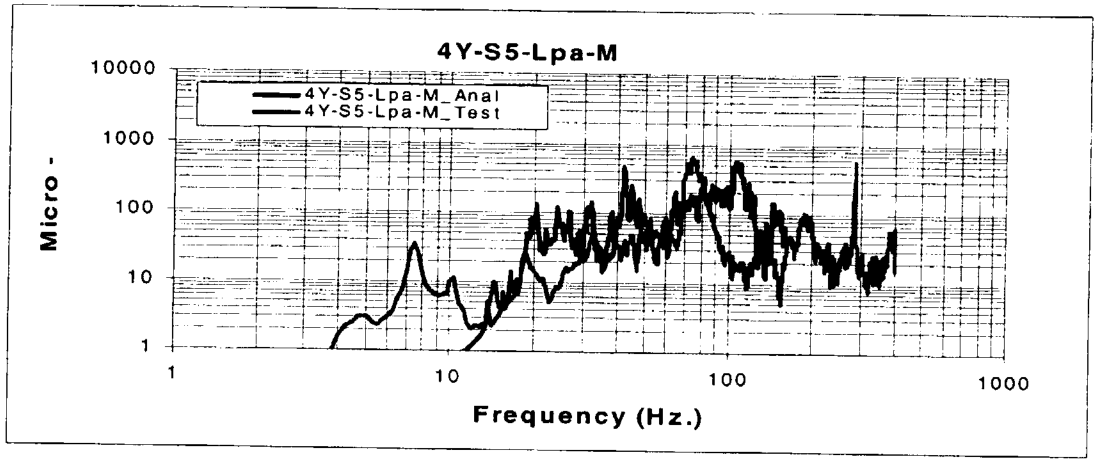


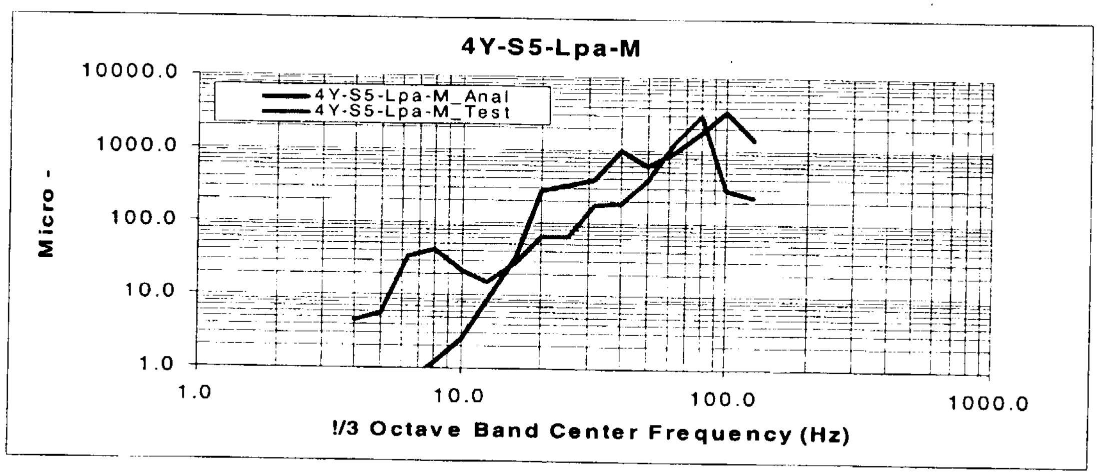
FEA Predicted vs Measured Response - F6 Rack



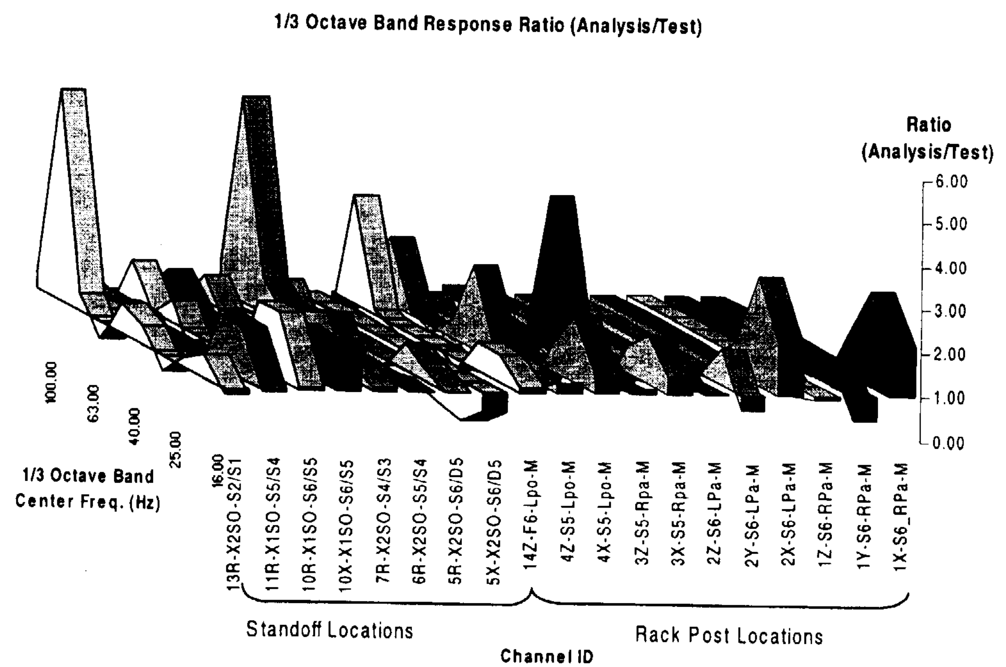


FEA Predicted vs Measured Response - S5 Rack



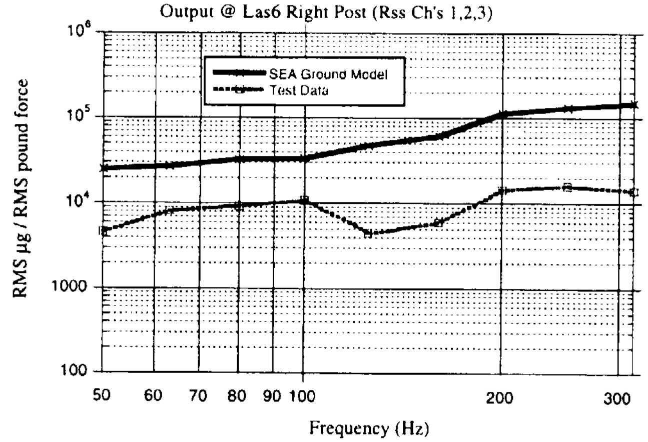


FEA Predicted Response / Measured Response (16-100 Hz)

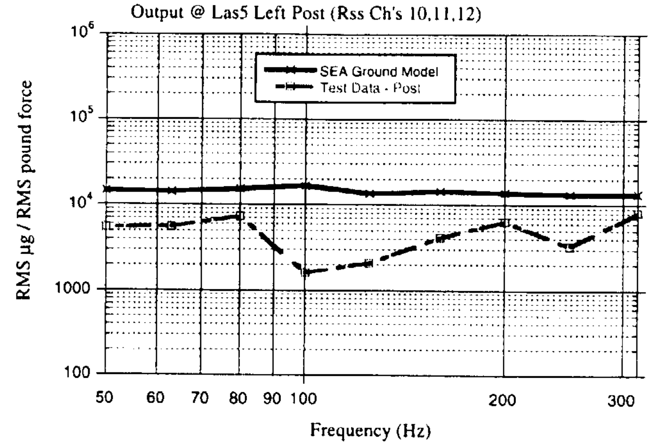


SEA Predicted vs Measured Transfer Functions

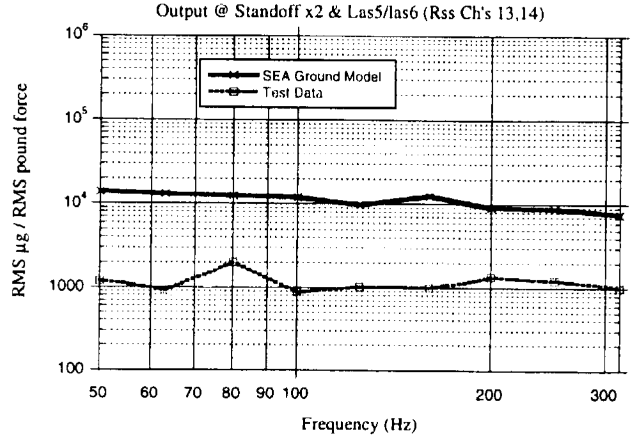
LAB Test Correlation with SEA Ground Test Model
Input @ Las6 Left Post (Ch 5)
Output @ Las6 Right Post (Rss Ch's 1,2,3)



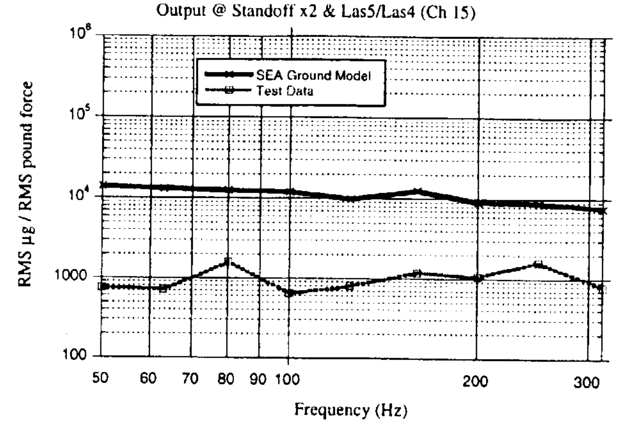
LAB Test Correlation with SEA Ground Test Model
Input @ Las6 Left Post (Ch 5)
Output @ Las5 Left Post (Rss Ch's 10,11,12)



LAB Test Correlation with SEA Ground Test Model
Input @ Las5 Left Post (Ch 11)
Output @ Standoff x2 & Las5/las6 (Rss Ch's 13,14)

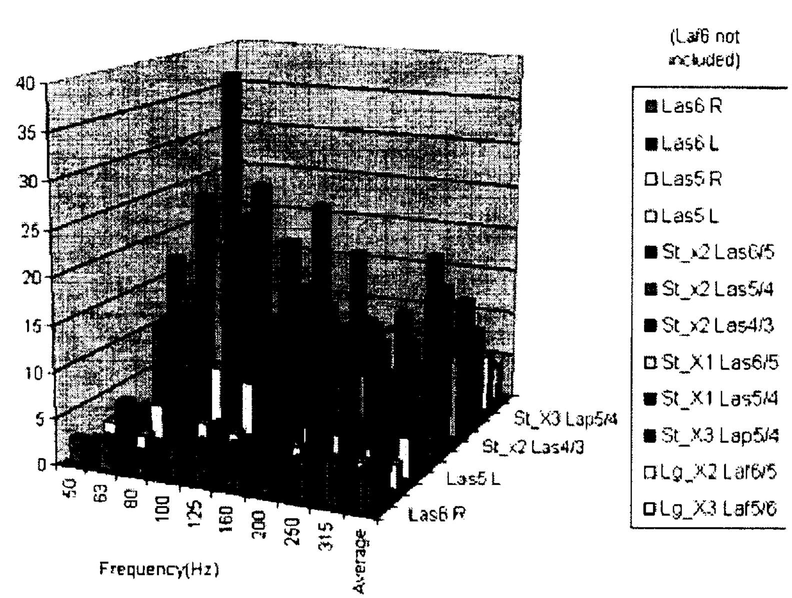


LAB Test Correlation with SEA Ground Test Model
Input @ Las5 Left Post (Ch 11)
Output @ Standoff x2 & Las5/Las4 (Ch 15)

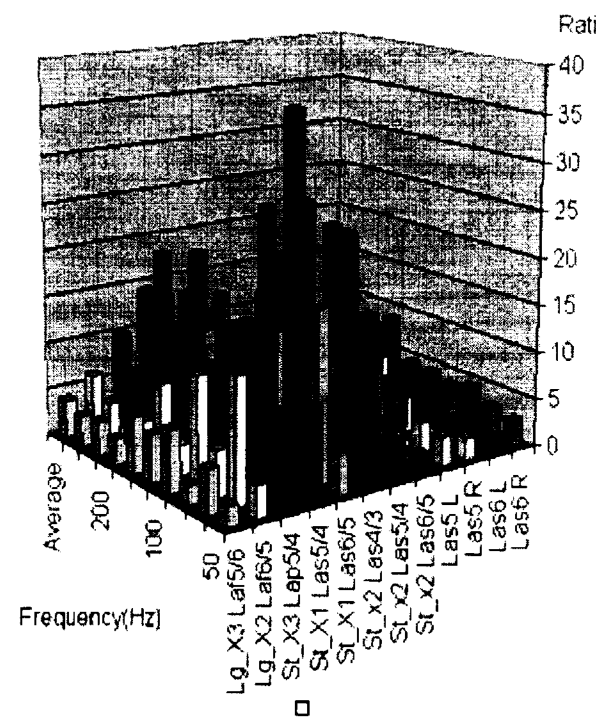


SEA Predicted Response / Measured Response (50-300 Hz)

SEA/TEST Response Ratio to DAC8 USL Equipment Operating (No CDRA)



SEA/TEST Response Ratio to DAC8 USL Equipment Operating



Results to Date

- Acceleration spectra show running speed and blade passage harmonics and flow induced broadband characteristics
- The CDRA pump adds to the other equipment induced responses in the 250 and 315 Hz 1/3-OB
- High frequency responses attenuate with distance for both rack and standoff positions
- Data below 12.5 Hz is plagued with narrowband components at 4, 5, 8, and 10 Hz
  - These frequencies are present to the same levels for each location in the x, z, y, and y directions, respectively, in both the operating test data and the baseline data
    - This indicates that the Lab was moving as a rigid mass on the elastic foundation provided by its supporting structure
    - The most likely sources of excitation at these frequencies are the external Lab support equipment (large vacuum pump, 2 chiller pumps, power supplies, and computers)
      - Note that USL external support equipment operational noise is transmitted to the Lab over acoustical and structural paths and through fluid lines to the USL internal piping systems
    - The internal Lab equipment itself is therefore not the source of these oscillations

Results to Date

- Impulse induced transfer functions are less than SEA analytical predictions by factors of 4-10 on average
  - These show that USL racks and structure are more heavily damped than assumed in analytical predictions
- Measured accelerations are less than SEA predicted responses by factors of 4-10 in the 50-300 Hz frequency range
- As the data evaluation process progresses, further useful information will be obtained
  - Disturbance force and acoustic power of equivalent rack sources will be extracted from measured responses using measured transfer functions
  - Structural damping and acoustical absorption characteristics will be quantified from transfer function data
  - Further model/test correlations will be possible for individual sources
  - USL data will be useful for future element verification and for sustaining engineering support activities

Assumptions & Conclusions

- Conclusions are based on the following assumptions
  - ARIS will meet its isolation specification
    - Note that ARIS attenuation above 100 Hz is ~ 50 instead of 500
  - Differences between on-ground and on-orbit rack-to-structure support conditions will not appreciably change rack response
    - Note that ground test racks were supported on longerons via knee braces and long rods, but on-orbit racks will be supported on standoffs via K-bars and pivot pins

- Conclusions
  - Based on the above assumptions, the USL ground test data indicate that USL equipment will meet vibratory microgravity requirements
    - Below 40 Hz, microgravity requirements are met without ARIS
    - Above 40 Hz, test data exceeds microgravity requirements by less than a factor of 20

Work Completed

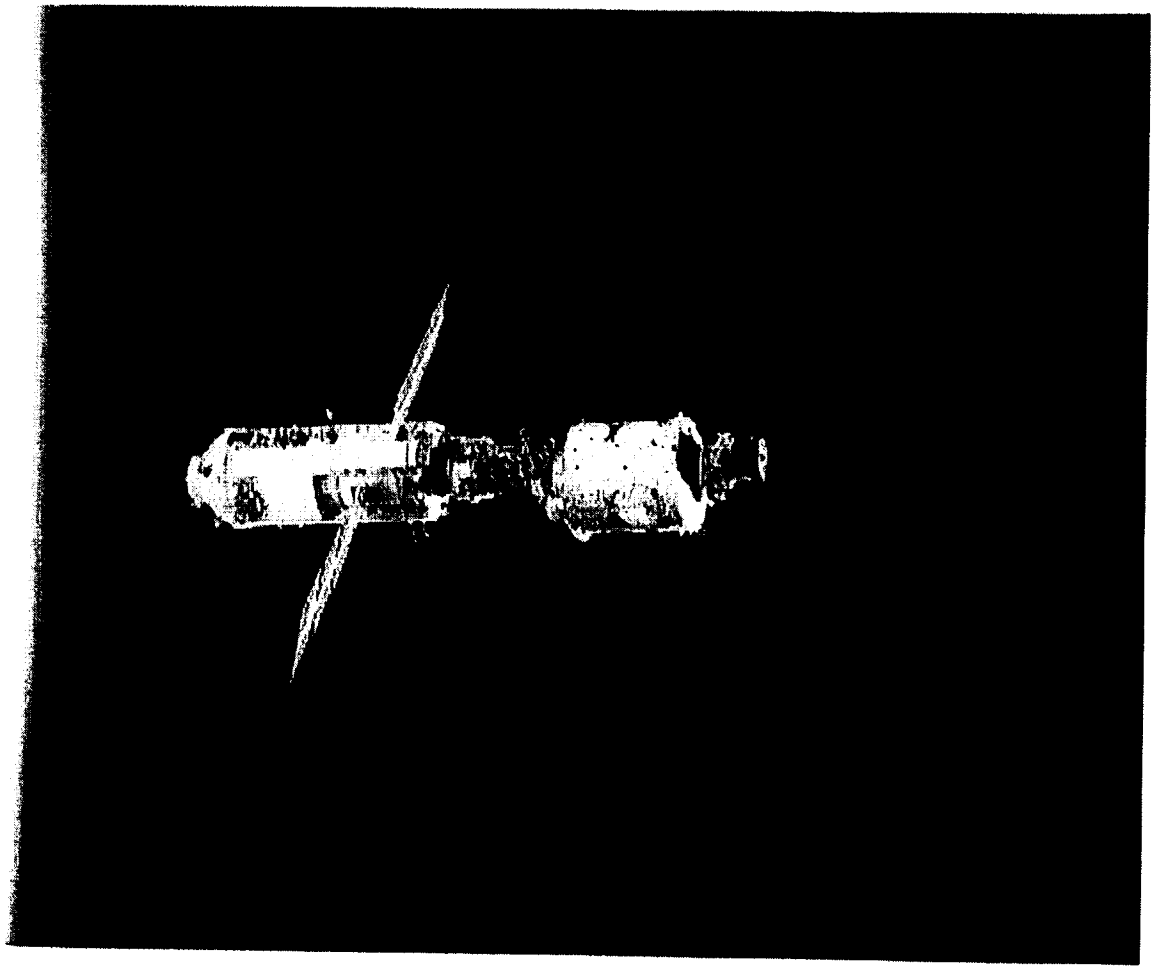
- Tests
  - US Lab Acoustics/Microgravity Tests
    - Individual intermittent equipment runs
    - Individual, combined, and all-source (except CDRA) continuous equipment runs
    - Transient and continuous sound source excitation runs
    - Transient and continuous mechanical source excitation runs
  - US Lab CDRA Tests
- Data reduction (narrowband & 1/3-OB)
  - All-source and CDRA induced acceleration and sound pressure responses
  - Baseline noise for the all-source and CDRA runs
  - Force-to-acceleration transfer functions (hammer and shaker induced)
- Model/test scaling for ground test configuration (FEA & SEA)
  - All-source and CDRA induced acceleration response
  - Force-to-acceleration transfer functions
- Quick look reports
  - Test data (narrowband & 1/3-OB)
    - All-source and CDRA induced acceleration responses
    - Force-to-acceleration transfer functions
  - Model/test scaling for ground test configuration
    - FEA acceleration responses
    - FEA force-to-acceleration transfer functions
    - SEA acceleration responses
    - SEA force-to-acceleration transfer functions

Forward Plan

Task	Time (weeks)	From/To	Person
● **Data reduction (narrowband & 1/3-OB)**	6	6-19/8-31	MM
■ Individual intermittent equipment induced accelerations	2	6-19/8-31	OC
■ Individual continuous equipment induced accelerations	1	6-19/8-31	EO
■ Sound power-to-acceleration transfer functions			
■ Sound power-to-sound pressure transfer functions			
■ Baseline noise			
■ Background noise			
● **Data extraction (useful for Sustaining Engineering & future element verification)**			
■ Separate acoustically and mechanically Induced accelerations	3	6-30/9-30	OC
■ Extract sound power and force disturbance functions	2	6-30/9-30	EO
■ Structural damping and acoustical absorption characteristics			
● **Model/test scaling for ground test configuration**	5	7-15/10-31	WJS
■ Sound pressure responses	6	7-15/10-31	VS
■ Sound power-to-acceleration transfer functions	2	7-15/10-31	OC
■ Sound power-to-sound pressure transfer functions	1	7-15/10-31	EO
■ Sound power disturbance functions			
■ Force disturbance functions			
● **Model scaling to on-orbit configuration**	1	11-1/11-15	WJS
	2	11-1/11-15	VS
● **Final reports**	4	11-15/11-30	ALL

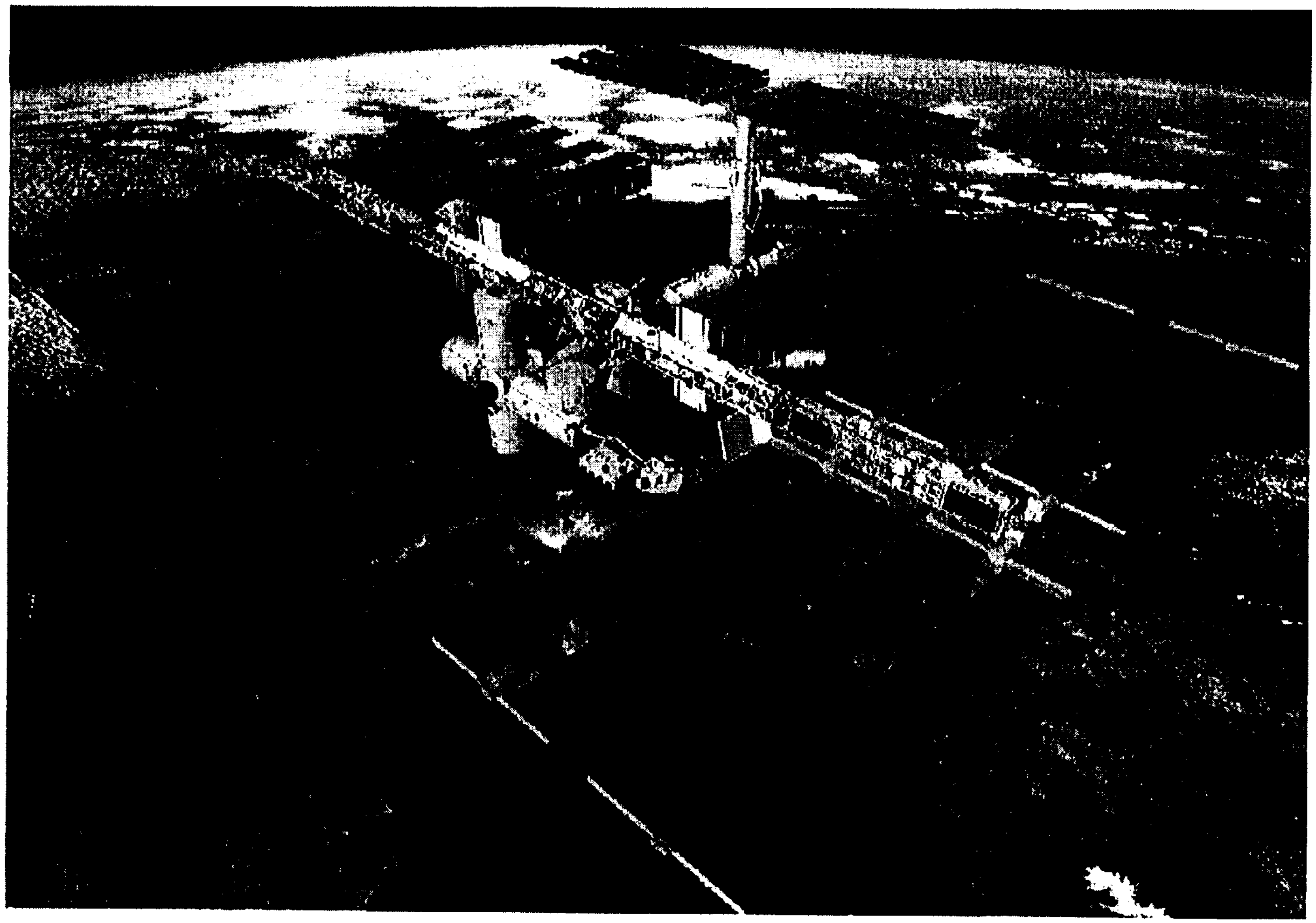
11-13 July 2000 *19th Microgravity Measurements Group Meeting* *Crenwelge/O'Keefe/Miller/Sun/Shekher*

The Present: Zarya & Unity (Dec. 1998)



S88E5156 1998:12:13 21:19:17

The Future (ca. 2005)



522/29

2001017754 512585 25PS

Paper Number: 22

Testing the BUNDLE experiment for microgravity disturbance characterization

Christy Gattis
NASA Marshall Space Flight Center
Huntsville, Alabama

Bob Engberg
NASA Marshall Space Flight Center
Huntsville, Alabama

A primary objective of the International Space Station is to provide a premier facility for microgravity research. There are many disturbances on board the Station that can disturb the quality of the microgravity environment, including disturbances caused by both system and payload hardware. Disturbances within experiments themselves can also affect the quality of their own environment.

The primary functions of the Bridgman Unidirectional Dendrites in Liquids Experiment (BUNDLE) are to melt, directionally solidify, and perform in-situ quench of metallic alloys, providing data to aid in understanding the effects of the microgravity environment on the characteristics of these processed metals. Quenching of the samples in the BUNDLE furnace is accomplished by rapidly introducing high pressure helium into the furnace chamber. This type of quench will induce sample vibrations which may be large enough to adversely affect sample quality. The primary objective of the test described in this presentation was to determine the acceleration imparted on the BUNDLE sample during helium quench. From this information, the science community can better assess whether this method of quench will allow them to obtain the data they need.

Utilizing breadboard hardware, the sample quench sequence was conducted. Data was collected from accelerometers located on the breadboard hardware and inside the sample cartridge. The test data indicated that the maximum acceleration achieved by the sample was 0.325 g, which is much higher than the desired microgravity (10^{-6} g) environment. However, this acceleration level occurred over a time period of less than 0.1 second. Because this time period is so short, there should be no detrimental effects to dendrite growth. This result was consistent with the observations of the experiment scientists, who are satisfied with the results of previous dendrite growth in this breadboard unit.

National Aeronautics and Space Administration
George C. Marshall Space Flight Center
Marshall Space Flight Center, AL 35812

Testing the BUNDLE Experiment for Microgravity Disturbance Characterization

Christy Gattis (ED21) and Bob Engberg (ED27)
NASA MSFC

Presented at the Microgravity Measurements Group Meeting
Cleveland, OH
July 11-13, 2000

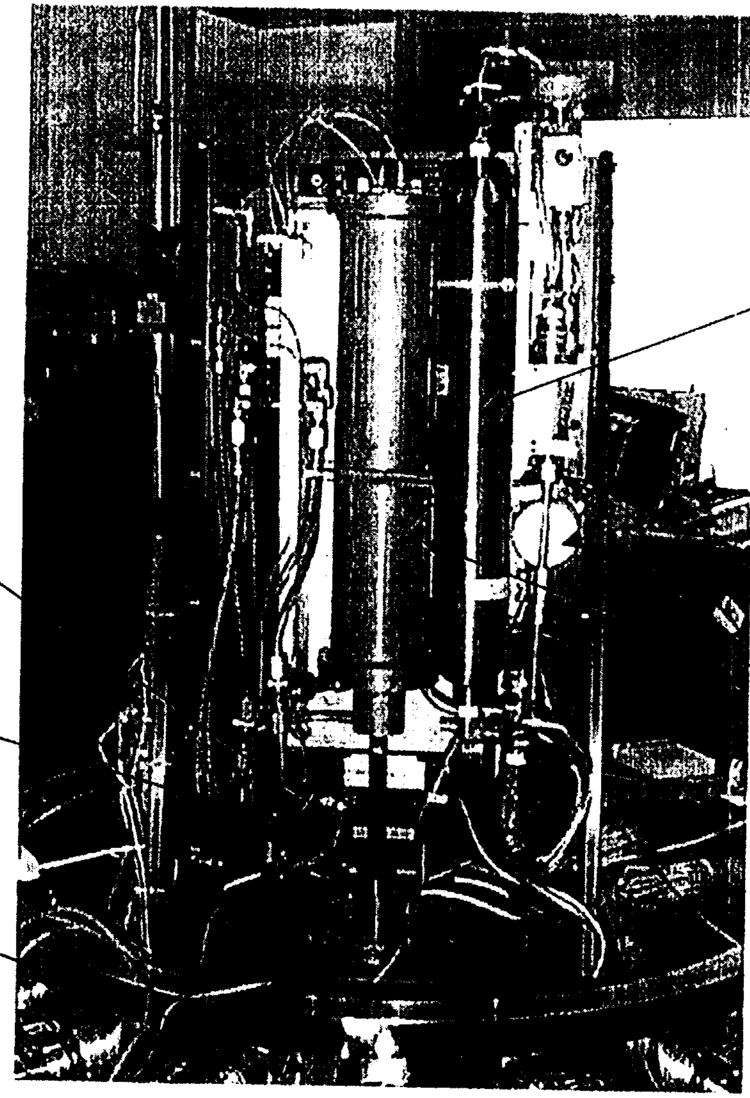
Microgravity on Space Station

- Primary objective of International Space Station is to provide a premier micro-g environment for materials science research
- Many components that operate on-board Station produce vibration during operation
- These vibrations can adversely affect the microgravity environment necessary to conduct valid experiments
- Vibrating components can be found not only in system racks, but within experiments themselves
- Component behavior should be characterized early to mitigate risk of exceeding disturbance requirements

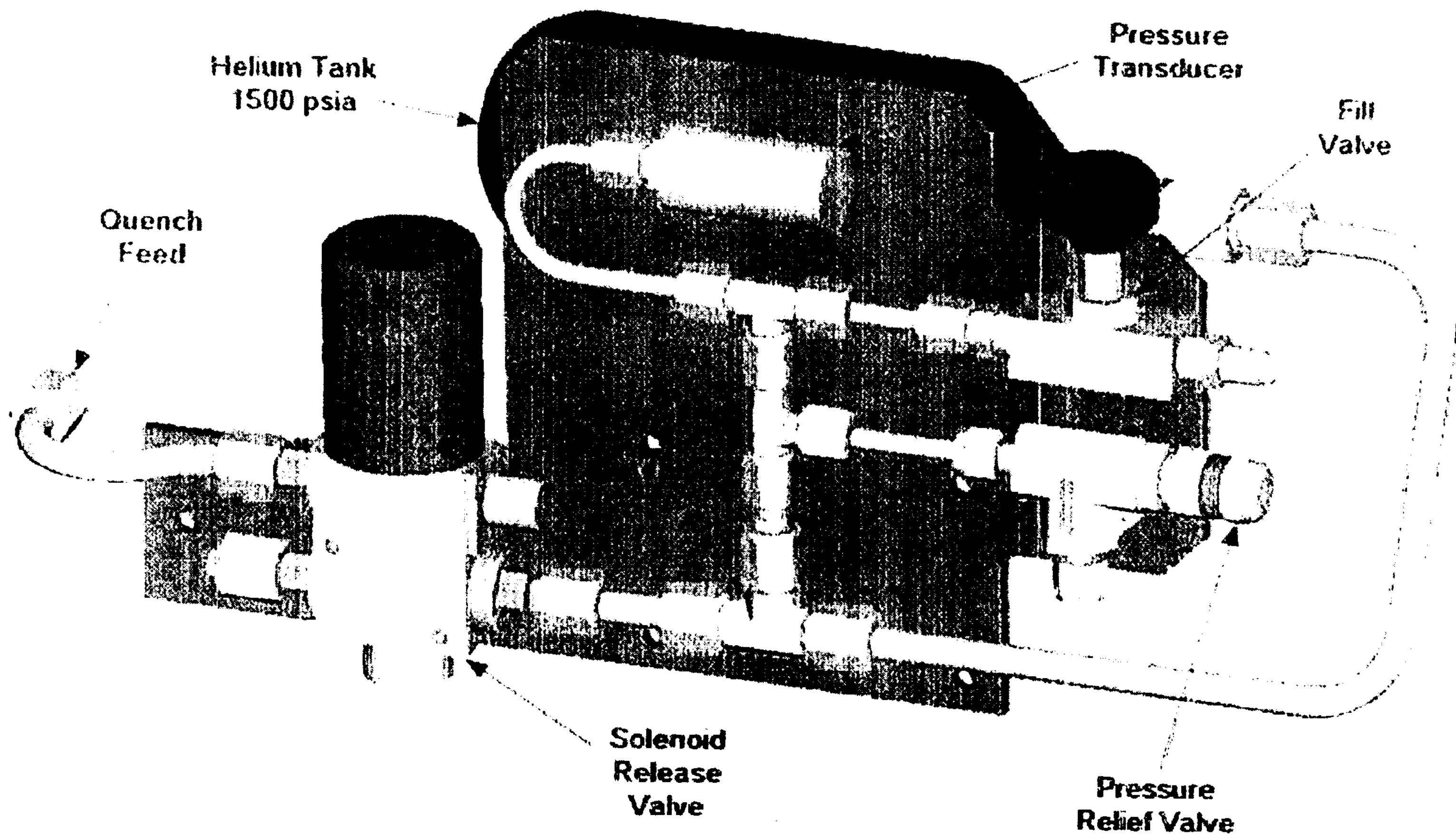
Test Article

- Test article was the Bridgman Unidirectional Dendrites in Liquids Experiment (BUNDLE)
- Primary functions of BUNDLE are to melt, directionally solidify, and perform in-situ quench of metallic alloys, in order to study the effects of the micro-g environment on the characteristics of these processed metals
- Quenching of samples is accomplished by rapidly introducing high pressure helium into the furnace
  - This method imparts vibration directly to the sample
  - Samples processed in breadboard unit have shown sharply delineated dendrite growth, proving efficacy of method
  - Test was conducted to investigate how this positive result was achieved in the presence of this disturbance

BUNDLE Breadboard



BUNDLE Quench System



MSFC ED21 Vibroacoustics

5

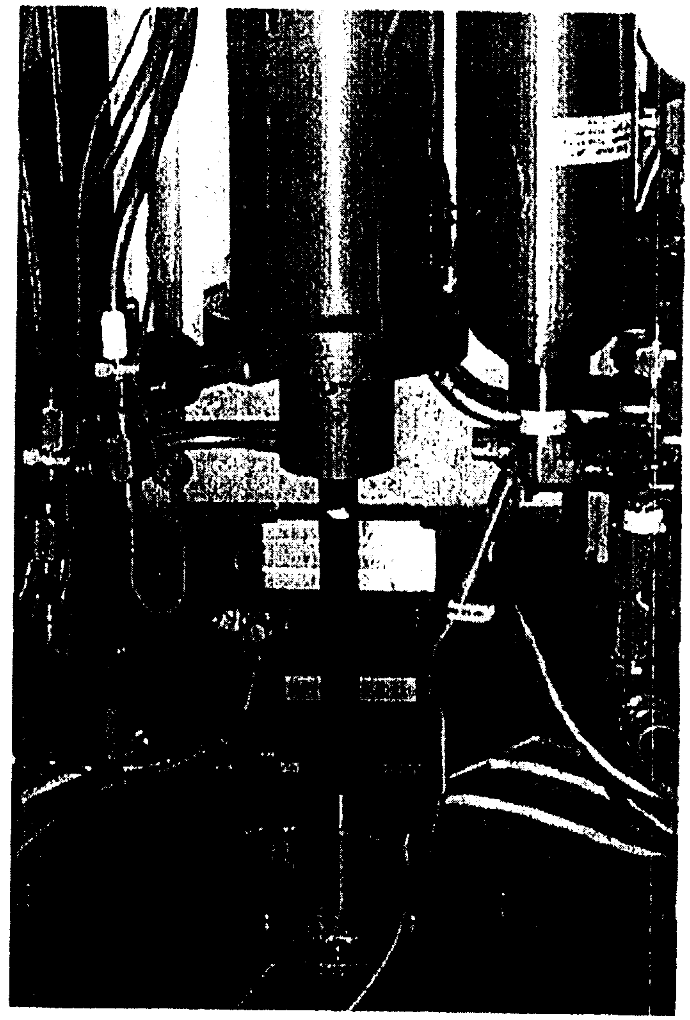
Test Objectives

- Primary Objective
  - Determine the acceleration imparted on the BUNDLE sample during helium quench
- Secondary Objectives
  - Determine the vibration characteristics of the translation gearbox, the helium line, and the valve during operation
  - Determine the vibration characteristics of the turbopump used with the BUNDLE lab vacuum chamber/bell jar for historical purposes

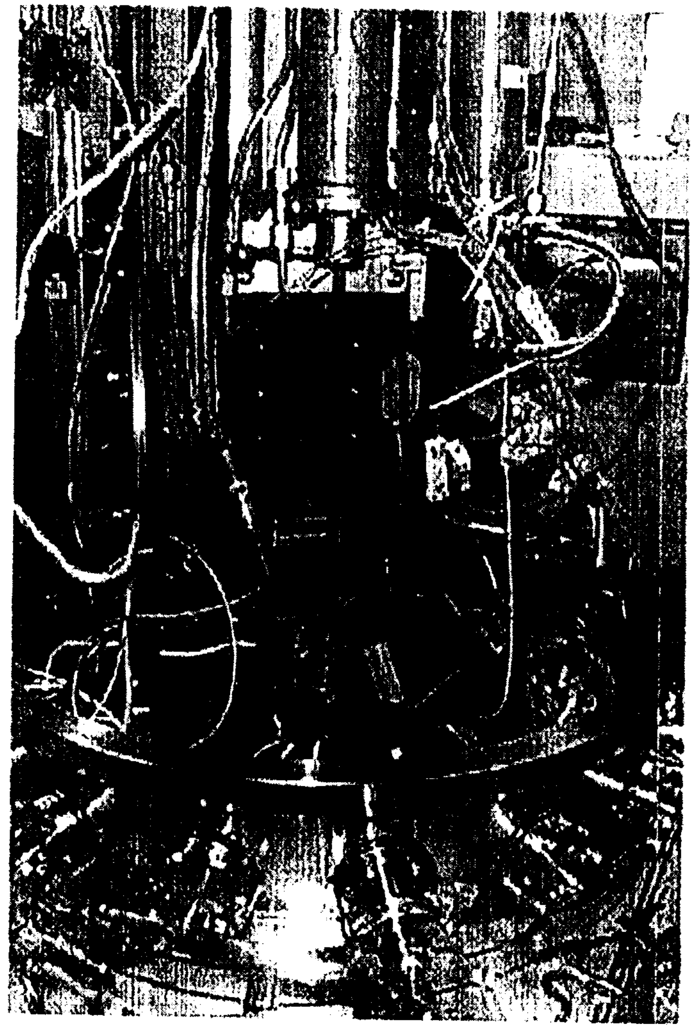
Test Article Details

- Sample Cartridge
  - Fabricated of POCO SFG-2 graphite instead of flight graphite for cost savings
  - Same dimensions as flight cartridge, 12.5” long, 0.5” outer diameter, 0.040” wall thickness
  - Filled approximately 2/3 full with lead
  - Installation same as for flight
- Breadboard Furnace
  - Functionally same as flight
  - Quench exhaust ports same dimensions and locations as flight, so quench dynamics same as flight
  - Boundary conditions/constraints for sample same as flight

Cartridge Mounted in Furnace



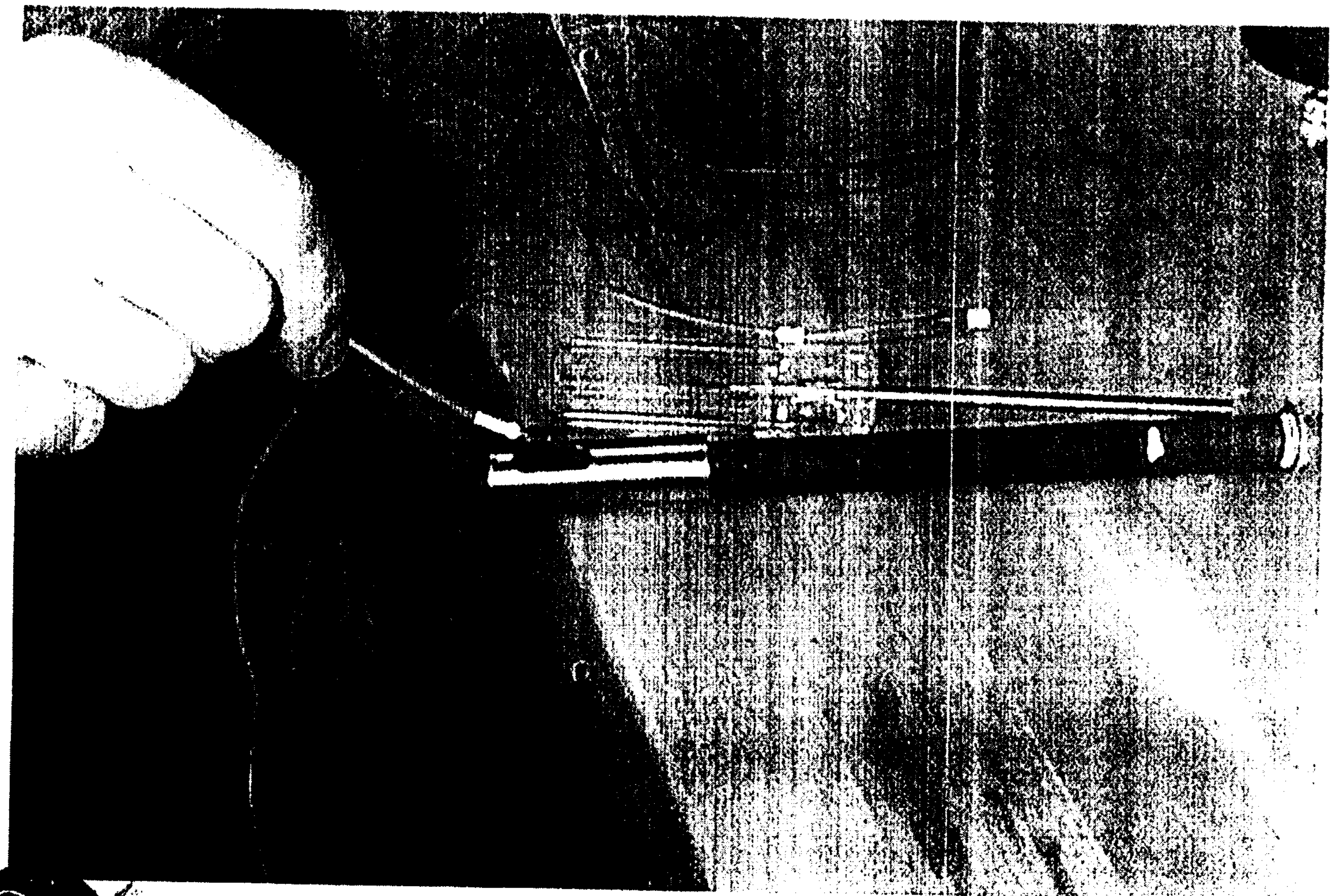
BUNDLE Breadboard



Test Instrumentation

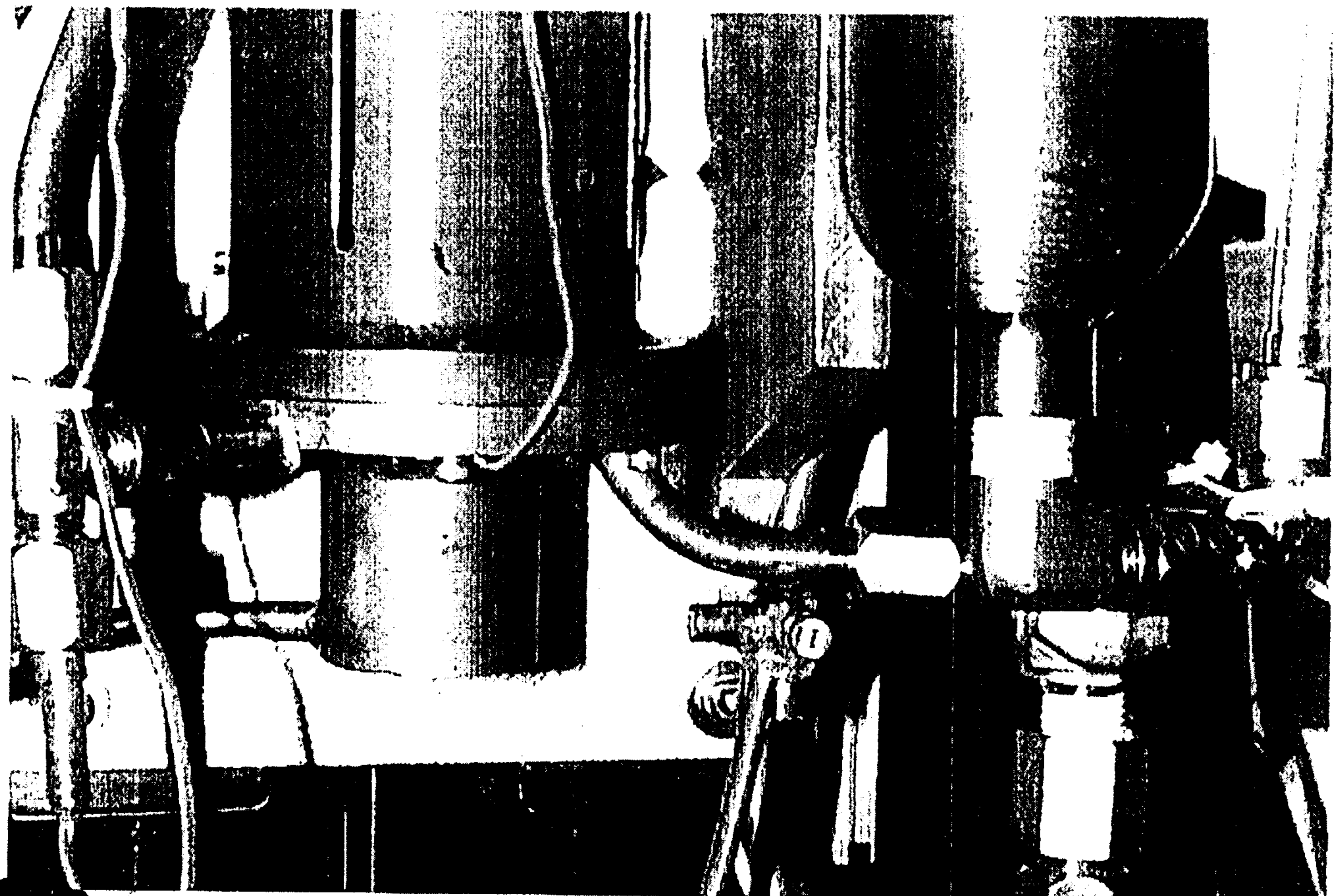
- Accelerometers
  - PCB Model 353B17 tri-axial accelerometers
  - One accelerometer mounted on hard line of fluid system, valve, and translation gearbox
- Accelerometers
  - Endevco Model 2222C uni-axial accelerometers
  - Mounted inside the cartridge, at the lead interface
- Data System
  - Record force and acceleration output on Sony PC116 DAT recorder
  - Outputs played back to HP 3566/67A DAS to produce time histories and spectral measurements

Accelerometer in Cartridge

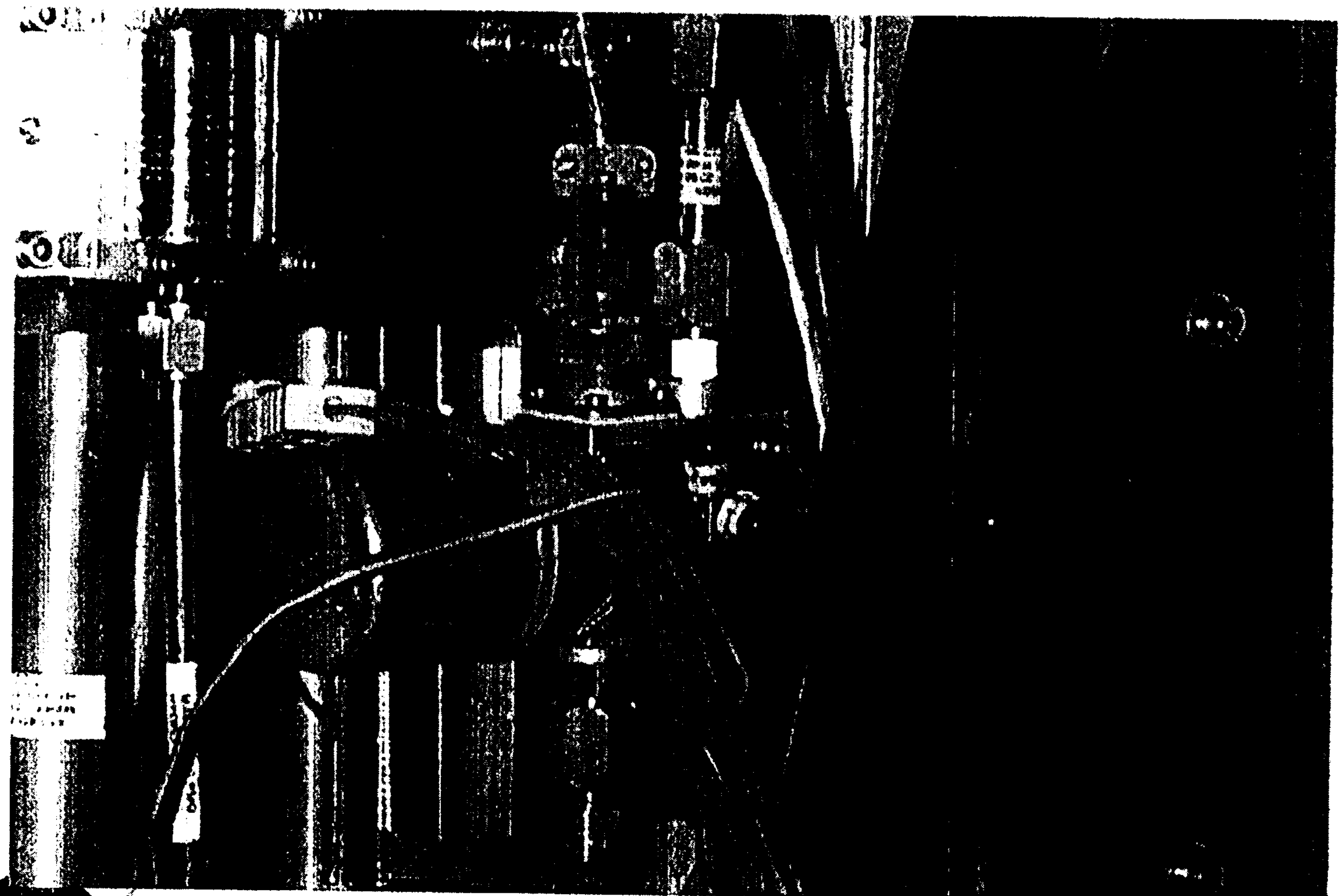


MSFC ED21 Vibroacoustics

Accelerometer on Helium Line



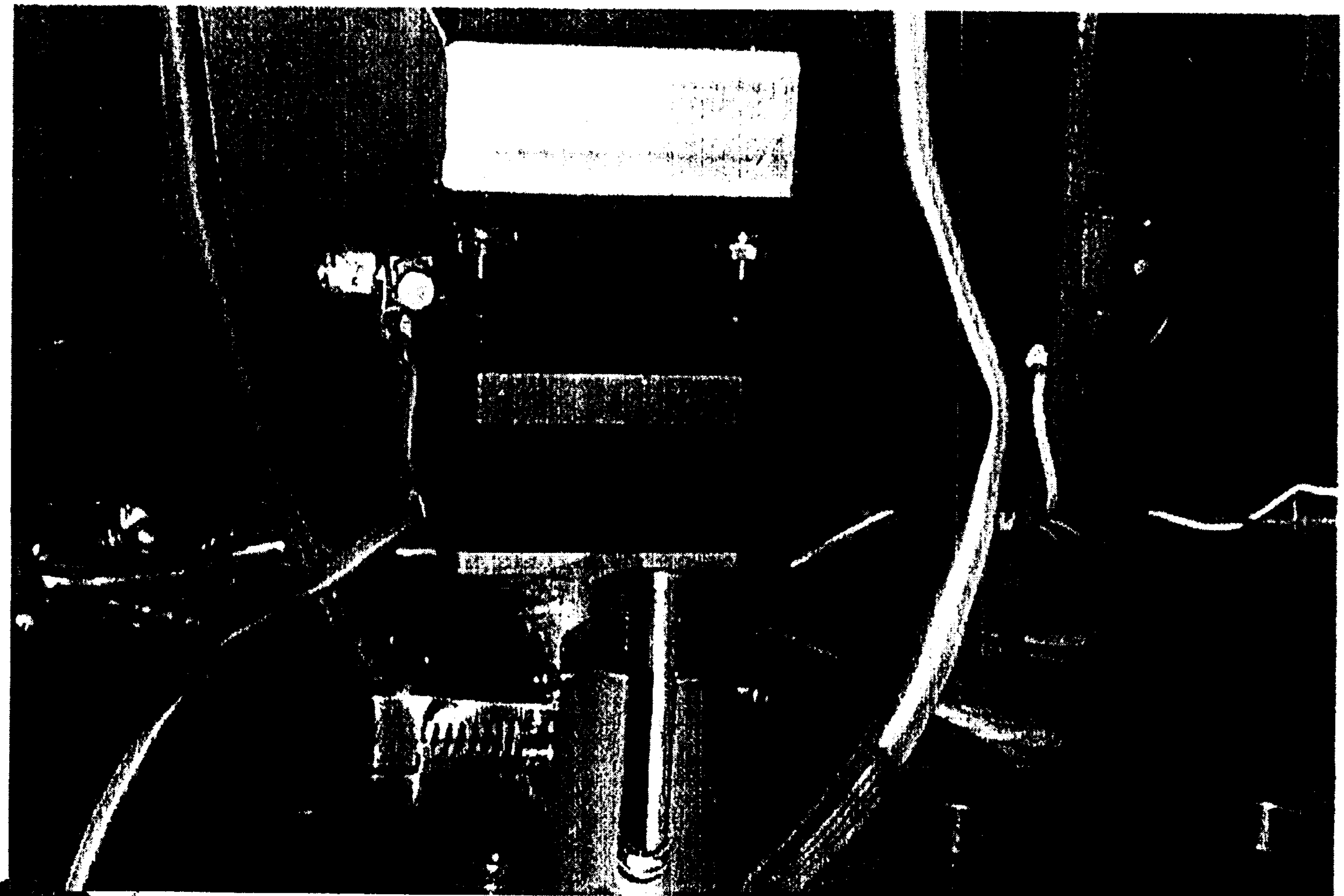
Accelerometer on Valve



MSFC ED21 Vibroacoustics

13

Accelerometer on Gearbox



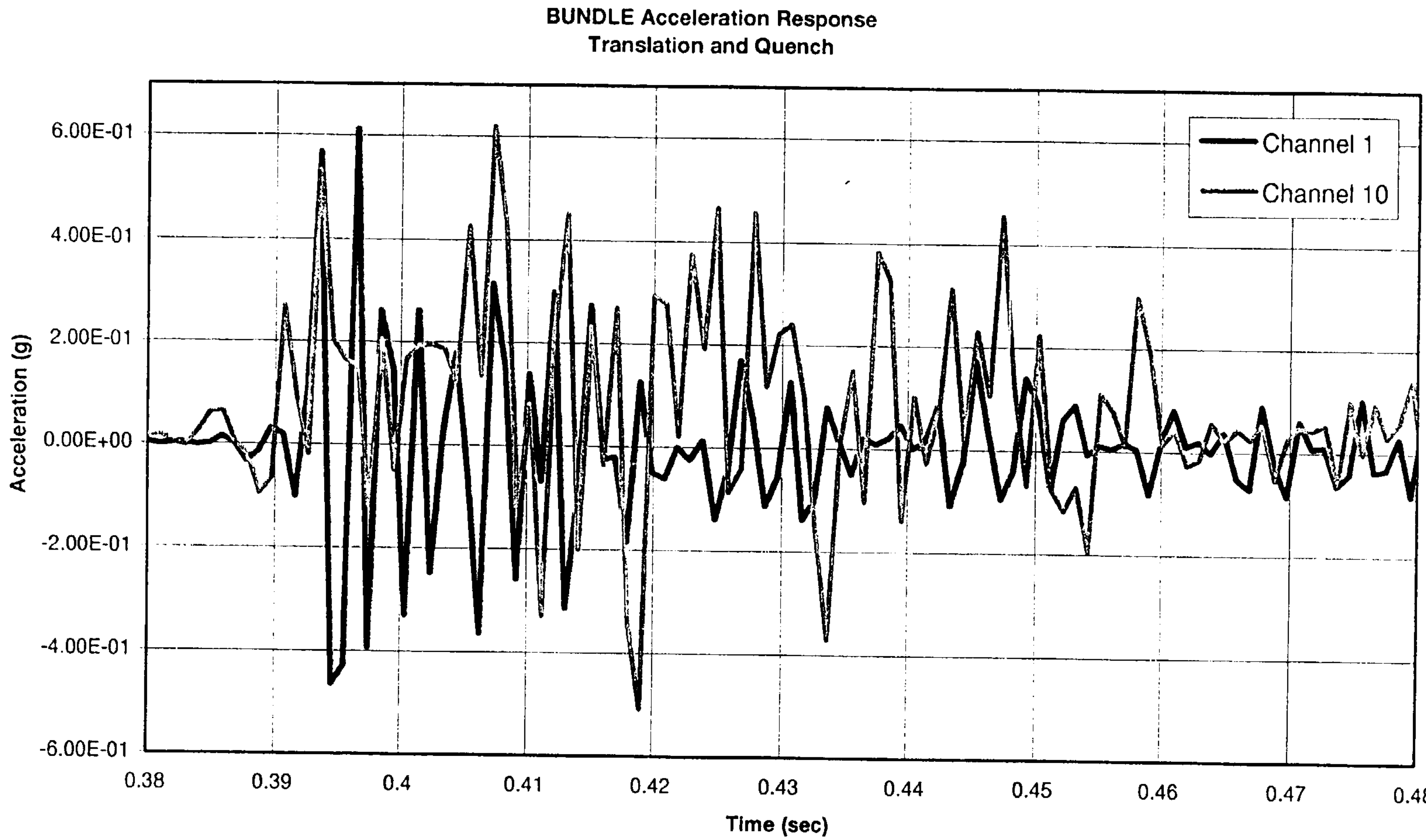
MSFC ED21 Vibroacoustics

14

Test Procedure

- Test article mounted rigidly in furnace
- Background measurements recorded from all accelerometers
- Water cooling system started, but no heat applied
- Data recording began for all accelerometers
- Furnace translated until sample accelerometer located in quench zone
- Quench initiated
- Furnace quench zone translated rapidly away from sample

Test Time History

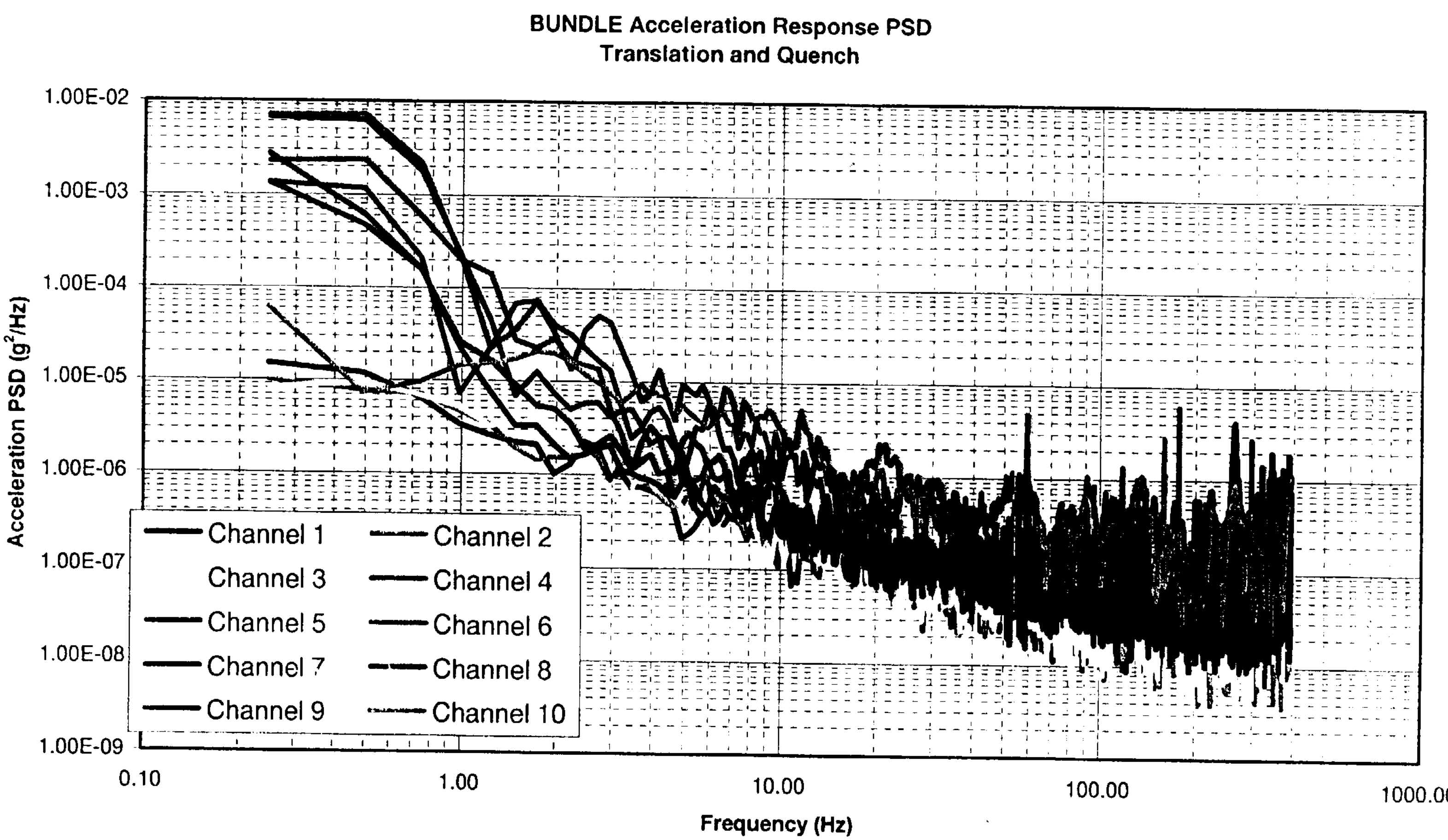


Note: Channel 10 inside sample

MSFC ED21 Vibroacoustics

16

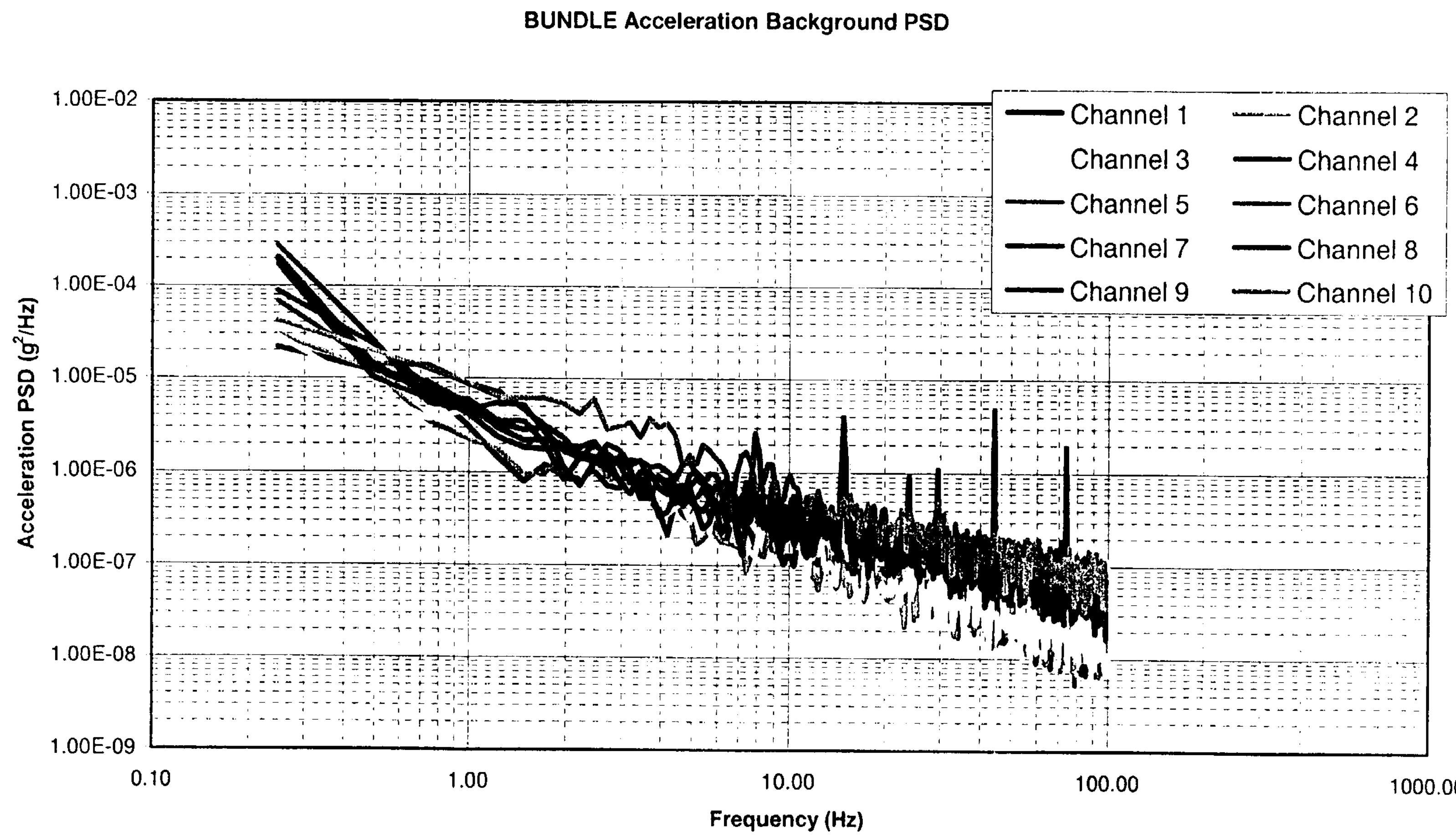
Power Spectral Density



MSFC ED21 Vibroacoustics

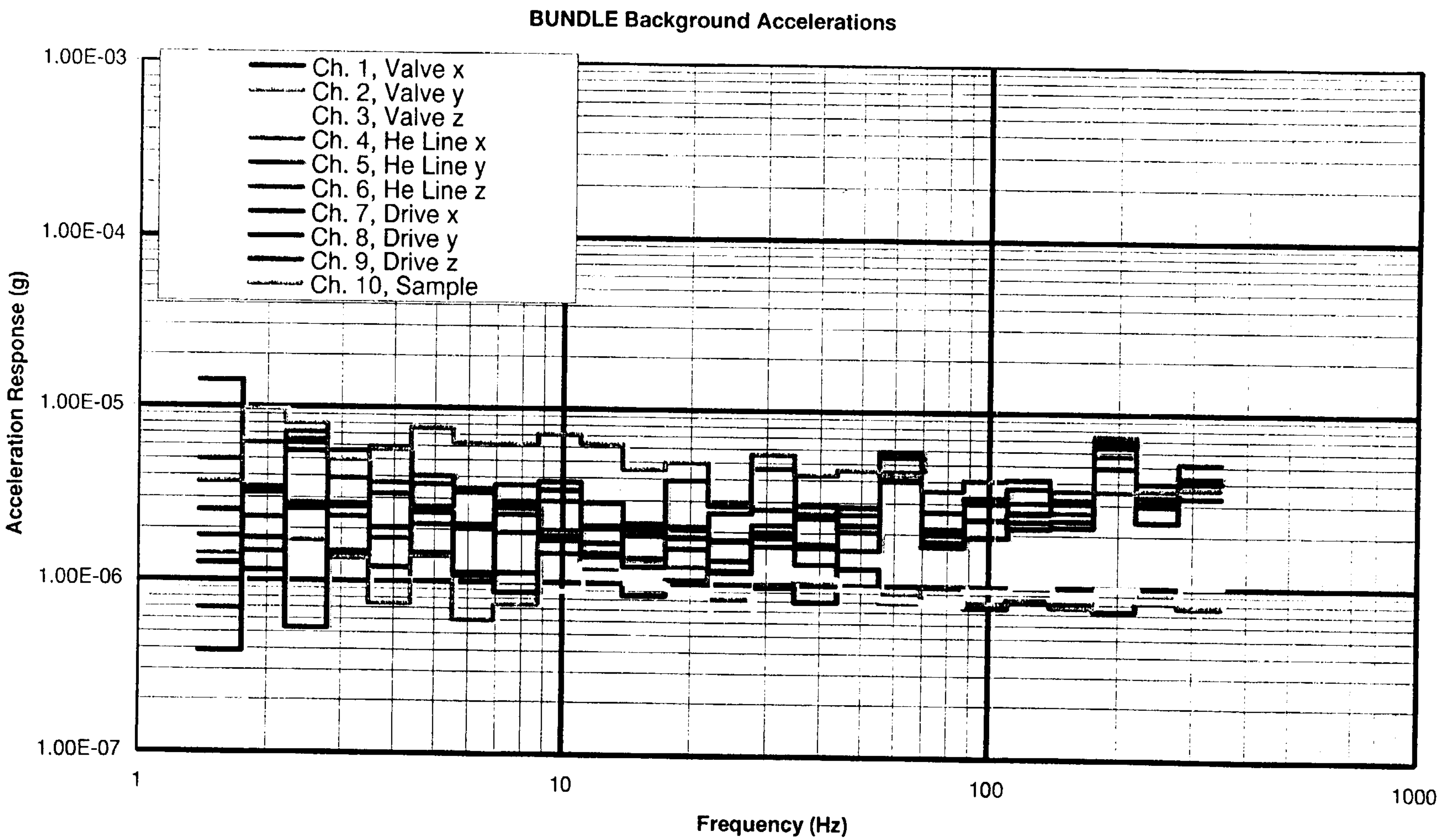
17

Power Spectral Density Background

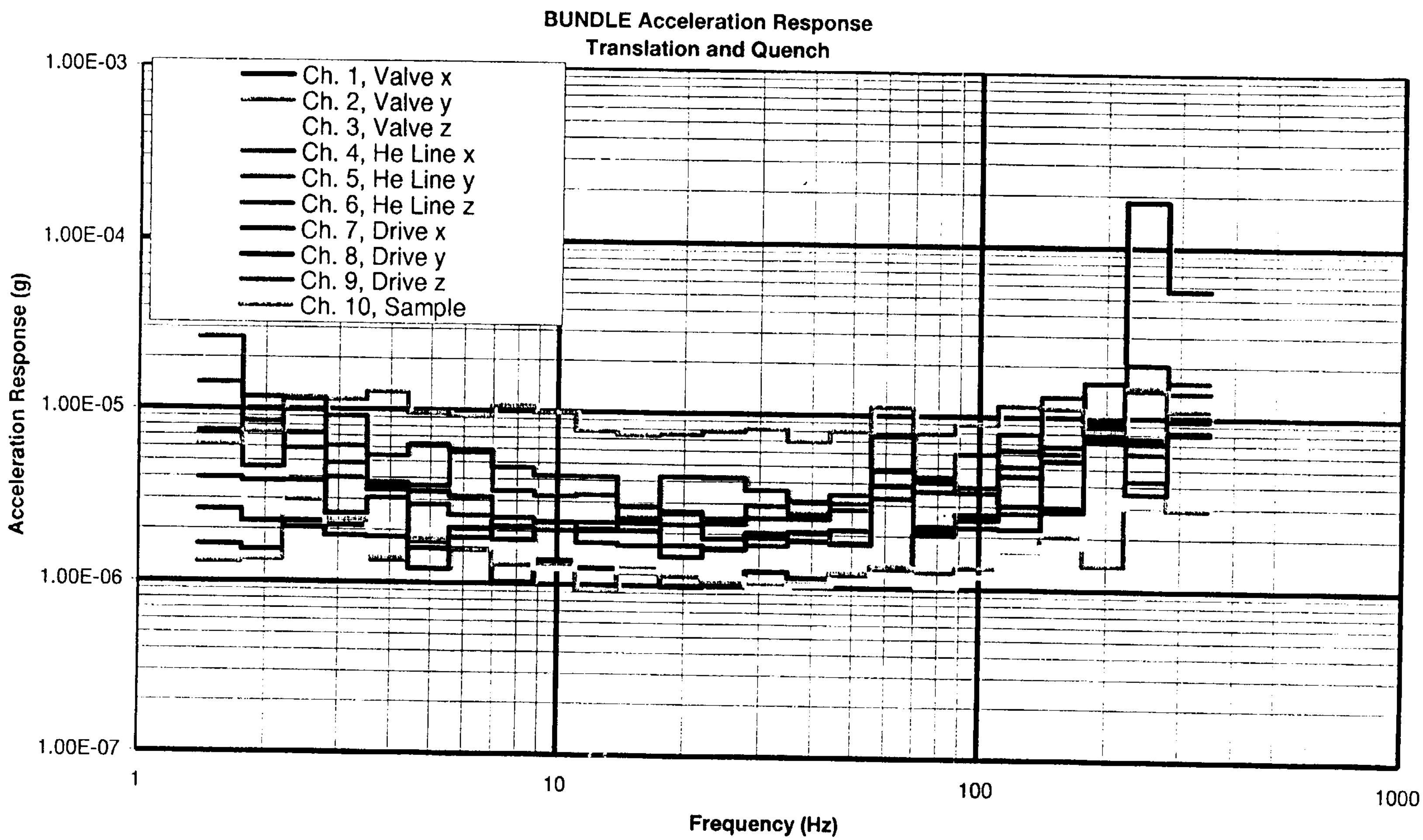


MSFC ED21 Vibroacoustics

One-Third Octave Background Data



One-Third Octave Data



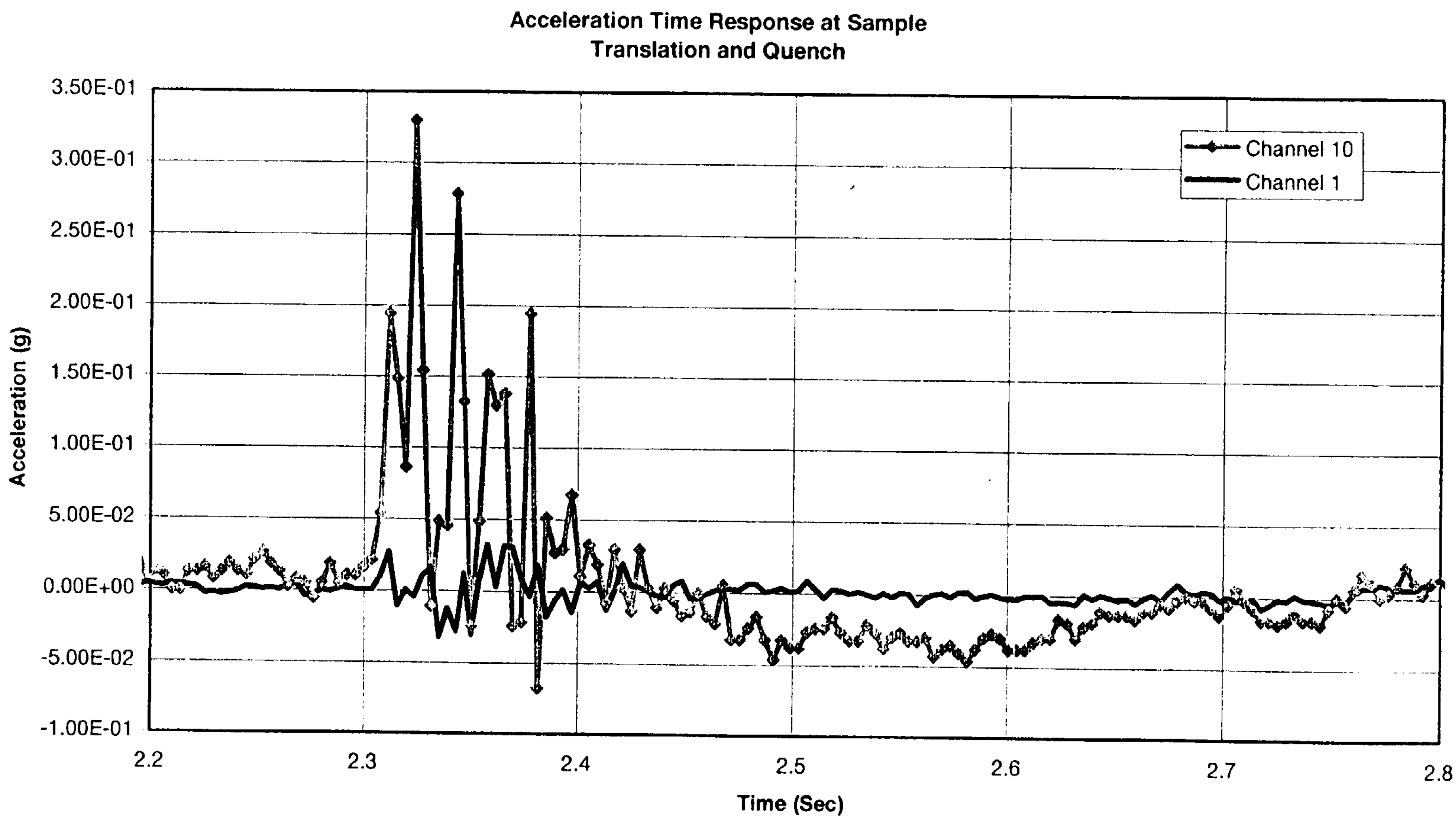
MSFC ED21 Vibroacoustics

20

Initial Analysis

- Vibration from quench expected to be obvious, especially at sample location
  - However, only "peak" in one-third octave data was not from the sample accelerometer location
  - Closer look required
- Concluded that event must have been masked by data reduction
  - Power spectrums and one-third octave analysis average responses over several minutes
  - Quench event was studied in closer detail

Quench Event Detail



Further Analysis

- In closer detail, 0.325 g maximum response became visible
  - Frequency of this event between 50 and 70 Hz
  - Time period was less than 0.1 second, which can be considered to be a transient disturbance
- Conclusion was that response was damped so quickly that no response was seen at sample

Results and Conclusions

- Test showed that some types of sample processing may be tolerant to large vibrations, if the time period is short enough
  - Further study into how different types of experiments respond to vibrations, both steady-state and transient
- Analyst must be aware of what type of disturbance events are anticipated
  - Measurement approach must be well-suited for random disturbances if transient disturbances are of interest
- Vibration produced by operation of BUNDLE translation gearbox, valve, and lab turbopump was recorded
  - This data can be used by other experiments as historical data for early disturbance analysis

30010/9755 512586

503/29 MGMG #19 16 PS

Paper Number: 23

Proposed ground testing standard methods & techniques

Thomas Goodnight
NASA Glenn Research Center
Cleveland, Ohio

The methodologies used for prediction for on-orbit microgravity environment needs to be ground validated. The data and models for such validation will be coming from diverse sources. No standardized methodologies have been validated which cover the entire 0 - 300 Hz range.

Current ground test data feeds into this process and therefore should be standardized to support both narrow and third octave band analysis.

Proposed Ground Testing Standard Methods and Techniques

A Microgravity Emissions Laboratory Perspective

Presented @ The μg Measurement Meeting

July 13, 2000

7735/Thomas W. Goodnight & 7735/Anne M. McNelis

NASA John H. Glenn Research Center

@ Lewis Field

Engineering Technical Services Division

MEL Perspective

- **The methodologies used for prediction for on-orbit micro-gravity environment need to be ground validated.**
- **The data and models for such validation will be coming from diverse sources.**
- **No standardized methodologies have been validated which cover the entire 0-300 Hz range.**
  - FEM & AutoSEA are the standard tools but do not overlay in the transition zone (typ. ~ 50 Hz) or where the transition zone actually occurs
  - FEM results are heavily dependent upon damping estimate and gives good narrowband modal response while AutoSEA maintains requirements for sufficient modal density for each third octave band .
- **Current ground test data feeds into these process and therefore should be standardized to support both narrow and third octave band analysis.**

Microgravity Emissions Lab
Current Method

- F=MxA (inertial forcing function)
- The diagonal mass matrix is currently measured and can be derived from FEA data if available.
- The acceleration vector at the combined hardware/fixture is least squared fit from 5 biaxial pairs (10 accelerometers total)
- Direct interface/science accelerations not currently made
- MEL inertial forcing functions are input to the assessment of the compliance with given μg allocation

MEL Methodology

- **Acquire Mass Moment of Inertia of component**
- **Acquire Background and Operation Emissions Acceleration Time Histories**
- **Compute narrowband Autospectra and FRF**
- **Apply frequency domain FORTRAN programs to compute rigid body forces & moments**
- **Compute actual narrowband and transform to 1/3 octave band forces and moments at CG of the component**

MEL Design Requirements

- **Design Requirement # 1 => uG measurement indicates minimum 10^{-7} g measurement floor**
- **Design Requirement #2 => Broadband measurement needs dictate minimal bandwidth 0-300 HZ (I.E. Sufficient sampling to calculate all third band octaves within range.) (note final bin centers at 315Hz is within range)**
- **Design Requirement #3 => generate inertial forcing functions for use of predictive technologies (e.g. FEA & AutoSEA) in assuring "good neighbor" policy and science requirements.**

MEL Design Parameters

- **Design Parameter #1 - least squares fit of 5 biaxial accelerometer pairs (10 accelerometers total) net "rigid body" acceleration vector of fixture and tested hardware.**
- **Design Parameter #2 - Measured Diagonal Mass Matrix (including fixture).**
- **Design parameter #3 - Data acquisition characteristics (e.g. synchronously sampling with sufficient resolution to support narrow and third octave band analysis.)**

MEL Design Constraints

- **Design Constraint # 1 - Maximum cable length fixed @ ~35 ft (10.5 m)**
- **Design Constraint # 2 - Facility modal content exists (e.g. two stage pendulum, cable response, etc.)**
- **Design Constraint #3 - Low Frequency apparatus acts as an inertial microphone**
  - isolated roof mount (i.e. pendulum pivot enclosure) provides input path from roof membrane/ wind gusts
  - cable is acoustic antenna
  - platform acts like a piston phone without the cylinder

Ground Testing Measurement System

- **Measurement Control Volume has been established as test article, MEL Apparatus, cable plus air volume immediately around the test article and MEL apparatus.**
- **The Boundary of the Measurement Control Volume can be fully documented:**
  - cable mounted load cell
  - sound intensity microphone pairs adjacent to test article
  - MEL Accelerometer Set
  - Test Article Response Accelerations

Ground Testing Acquisition System

- **Diverse Instrumentation in-use and available for the model correlation/validation effort/publication.**
  - accelerometer (limited by number of amplifier channels)
  - cable load transducer
  - MEL transducers
  - Sound Intensity Microphones
  - impedance measurements are planned for rack interfaces
- **All data acquired on time consistent basis on HP VXI data harvester and processed using MTS/I-deas Test Data Analysis Software (TDAS) and some associate FORTRAN and program files**
- **Current processing nets narrow band spectral results.**
- **Currently all raw data (i.e. time histories are retained)**

MEL Data System Parameters

- **Systems are oversampled (1280 samples/sec) to cover third band octave bins to 300 Hz (i.e. 315 Hz third octave bin required to complete range)**
- **Current acquisition settings net .156 Hz Δf bin resolution**
- **Acquire time/number of frames are dependent on stability of average/ repeatability for transient events.**
- **All data is acquired on a time consistent basis.**
- **Micro-Gravity Emissions Lab Signal to Noise Ratio improvement program for 10^{-7} g's measurement floor and 1-300+ Hz Bandwidth**
  - Instituting analog low-pass filters to eliminate channel saturation and proper scaling for light weight configurations

Ground Test Environment Noise Inputs

- **Potential Environmental Data corrupters**
  - In-situ noise sources (transformer, sump pumps, steam condensant pump, lights, steam pipes, a/c, stereos, data station, Slamming doors, etc)
  - External noise sources (i.e. roof mounted enclosure inputs) wind, aircraft noise, courtyard activities, wind tunnel operations
- **Planned Capital Improvements**
  - Blanket room (answering the question does acoustic energy truly exist from 0-300 Hz
  - Doghouse Isolation/insulation-Introduction of Air bags lowers mid frequency response but introduces modal content at ~ 3 Hz
  - 750 kVA High Voltage transformer removal

Microgravity Emissions Lab Environmental Controls

- **Current Environmental controls are:**
  - **Facility lockdown (i.e. limited access during testing),**
  - **Environmental control,**
  - **transformer shutdown, (unit is turned on when needed for wind tunnel operations)**
  - **shutdowns in general, plus,**
  - **testing after hours if necessary**
    - limited wind tunnel operations
    - quiet outside conditions required

Ground Test Standards Summary

- **Microgravity Emission Lab to be in final configuration this calendar year.**
- **Test parameters are sufficient for Test Reporting.**
  - *Minimum Format standards* for narrow band data and minimal Δt for database archival and simulation *should be consistent and agreed to by group*
- **MEL characteristics are part of data set**
- **Implementation in FEM /SEA predictions final test for forcing function sufficiency**
  - inertial forcing functions in the time domain need to be implemented
  - MEL characteristics plus environmental noise effect on process results need to be known

Conclusions

- **Current processing parameters net reasonable spectral resolution for test results.**
- **FEM and SEA processing of these inertial forcing function data sets required to access consistency with μg allocations/good neighbor policy plus assurance of applicable science requirements.**

3001019756

51258 7
10P

534/29

Paper Number: 24

In flight measurement results of microgravity space platform Photon #12 of September 1999 and plans on modified Photon-M #1 flight

Valentin F. Agarkov
Central Specialized Design Bureau
Samara, Russia

O. L. Mumin
CSRI Electropribor
St. Petersburg, Russia

In the 9th of September 1999 a specialized automatic microgravitational platform Foton #12 was launched from Russian cosmodrome "Plesetsk". The platform carried microgravity-related scientific equipment from Russian Space agency, ECA, KNESS, and DARA. Microgravity measurements were conducted with Russian equipment "Sinus-12". "Sinus-12" is equipped with four tri-axial accelerometers.

The Space Platform successfully carried out its task. Reentry vehicle landed softly on time. Scientific equipment was handed back to the above mentioned Space agencies.

The results of microgravity measurements during this flight are published in this report. A short commentary is given about the next flight of "Foton-M" #1 which is planned to fly in 2002.

IN-FLIGHT MEASUREMENT RESULTS OF MICROGRAVITY SPACE PLATFORM "PHOTON" №12 OF SEPTEMBER 1999. PLANS ON MODIFIED "PHOTON-M" №1 FLIGHT.

V.F.Agarkov, V.D.Kozlov, O.L.Mumin

Automatic specialized microgravity platform "Photon" №12 was launched from the Russian spaceport "Plesetsk" on the 9-th of September 1999. The platform was equipped with experimental gear of the Russian aviation-space agency, ESA, CNESS and DARA for microgravity research. The space platform completely performed its mission.

The re-entry capsule was softly landed on the Earth at the pre-set time. The experimental gear was given to the representatives of the specified space agencies.

Microgravity measurements were performed by the Russian system "Sinus-12K" developed by TsNII "Elektropribor" and incorporating 4 three-axis accelerometers of MSTA type. MSTA accelerometer (magnetic spherical three-axis accelerometer) with magnetic proximity suspension of the levitating spherical rotor. Accelerometer performances are changed over a wide range by means of changing electronic components parameters of the suspension.

ESTA accelerometer (electric spherical three-axis accelerometer) is a spherical rotor levitating over the electrical field of the suspension. There is a possibility to bring its sensitivity to $1\cdot10^{-10}$ g. In comparison with "Sinus-6K" system used in the previous flight on "Photon" №11 the number of measuring channels was increased from 6 to 12, accelerometers sensitivity was increased up to $1\cdot10^{-7}$ g, microaccelerations measuring time was increased from 32 hours to 240 hours.

Actually the total measuring time during "Photon" №12 flight equaled 65 h. 2 min. 46 sec.

Diagram of accelerometers positioning relative to the coordinate center and axes of the platform is shown in Fig. 1. Basic characteristics of "Sinus" system are given in table 1.

There were 12 in-flight runs of measurements executed over frequency ranges 0-0.1 Hz, 0.2-10 Hz, 10-300 Hz.

Results of the measurements over ranges 0.2-10 Hz and 10-300 Hz are close to the similar ones obtained on "Photon" №11 in 1997. Results of the measurements over the range 0-0.1 Hz show that quasistationary accelerations don't exceed some micro-g units all over the flight. Results of the measurements executed in the 7-th run of measurements of 19.09.1999 – 20.09.1999 are given in Fig. 2 and Fig. 3.

These are the best achieved results. Their consideration shows that at least during 10 hour flight the accelerations didn't exceed $6\cdot10^{-6}$ m/s or $\sim6\cdot10^{-7}$g. It confirms our theoretical conclusions that carrying out certain feasible technical actions it can be achieved that during next "Photon" flight microgravity wouldn't fall outside the limits of minus seven exponent.

Results processing of measurements over 10-300 Hz frequency range is shown in Fig. 4 as spectral components amplitudes on projection of X accelerations. These results were obtained during the second run of measurements of 13.09.99 and are typical for the whole flight. Considering the diagram it is seen that maximum microacceleration is achieved over frequency range 190-265 Hz. The sources of these vibroaccelerations are mechanical units mainly the ones placed in the re-entry capsule. Maximum achievable values are $4\cdot10^{-3}$ m/s ($\sim4\cdot10^{-4}$g).

"Sinus-12K" system was first used to measure accelerations at the descent leg. Figures 5-8 represent results of the platform parameters measurement during break engine operation of 24.09.1999. It showed wide potentialities of the "Sinus" system.

Fig. 5 – measurement of the velocity in the orbital motion direction (axis X of the accelerometer).

Fig. 6 – acceleration in the orbital motion direction.

Table 1

Parameters	Sinus-12	Sinus-15
Accelerometers	MSTA, (ESTA)	MSTA, ESTA
Quantity of measuring channels	12	15
Resolution	$1\cdot10^{-6}$g - $1\cdot10^{-7}$g	$1\cdot10^{-6}$g – 1 piece, $1\cdot10^{-7}$g – 2 pieces, $1\cdot10^{-8}$g – 2 pieces
Time of microaccelerations registration	240 h	400 h
Computer	On base of OCTAGON SYS cards	On base of OCTAGON SYS cards
Weight	3 kg	5 kg
Power consumption	15 W	30 W
Measuring of angular velocity	no	yes
Measurement ranges	0-0.1 Hz	0.2-10 Hz, 10-300 Hz

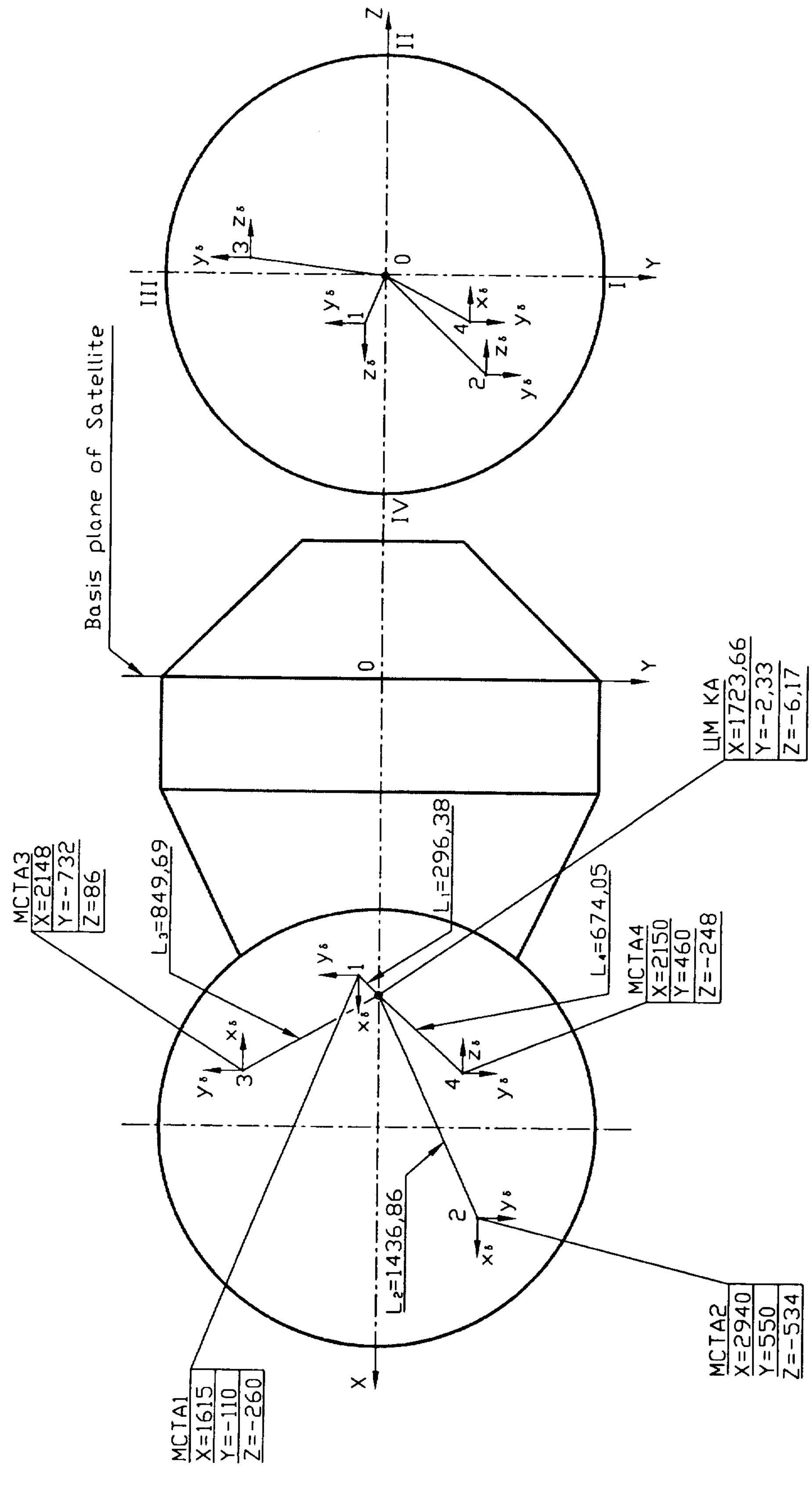
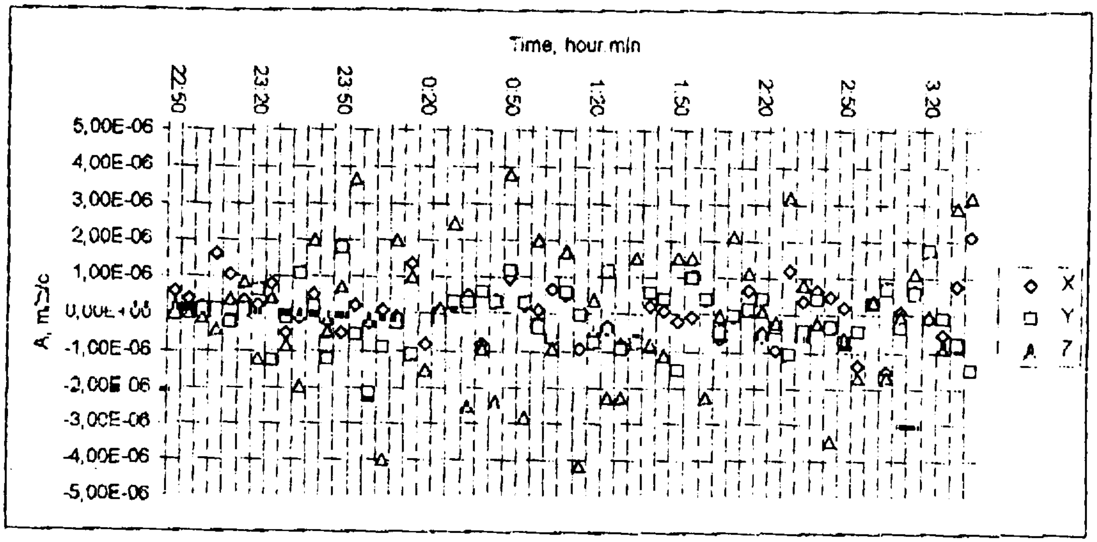
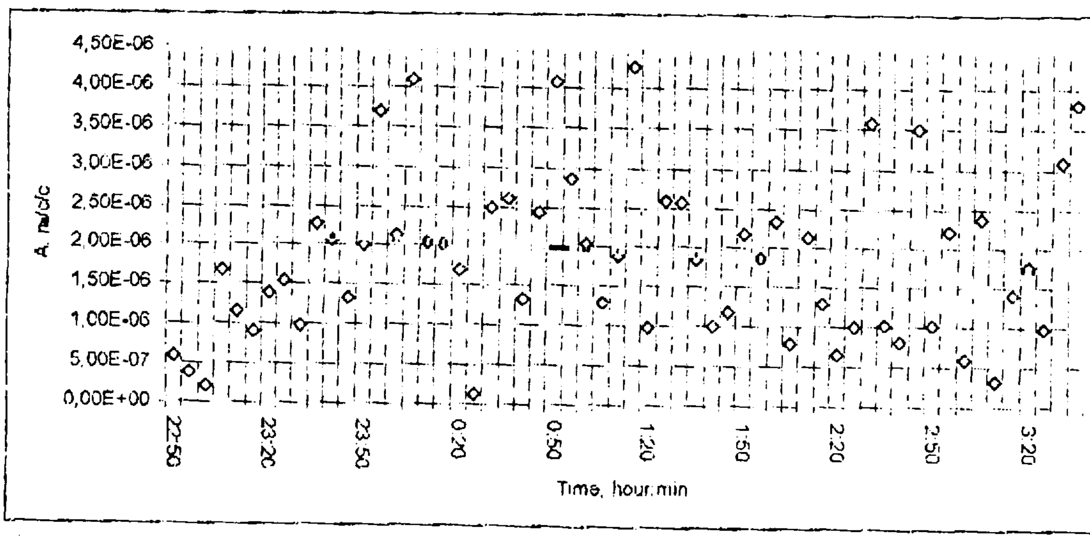

Basis plane of Satellite
ЦМ КА
X=1723,66
Y=-2,33
Z=-6,17
MCTA1
X=1615
Y=-110
Z=-260
MCTA2
X=2940
Y=550
Z=-534
MCTA3
X=2148
Y=-732
Z=86
MCTA4
X=2150
Y=460
Z=-248
L₁=296,38
L₂=1436,86
L₃=849,69
L₄=674,05
I
II
III
IV
X
Y
Z
0

Fig 1



Time, hour.min
22:50
23:20
23:50
0:20
0:50
1:20
1:50
2:20
2:50
3:20
5,00E-06
4,00E-06
3,00E-06
2,00E-06
1,00E-06
0,00E+00
-1,00E-06
-2,00E-06
-3,00E-06
-4,00E-06
-5,00E-06
A, m/c/c
X
Y
Z

Fig. 2



4,50E-06
4,00E-06
3,50E-06
3,00E-06
2,50E-06
2,00E-06
1,50E-06
1,00E-06
5,00E-07
0,00E+00
A, m/c/c
22:50
23:20
23:50
0:20
0:50
1:20
1:50
2:20
2:50
3:20
Time, hour.min

Fig. 3

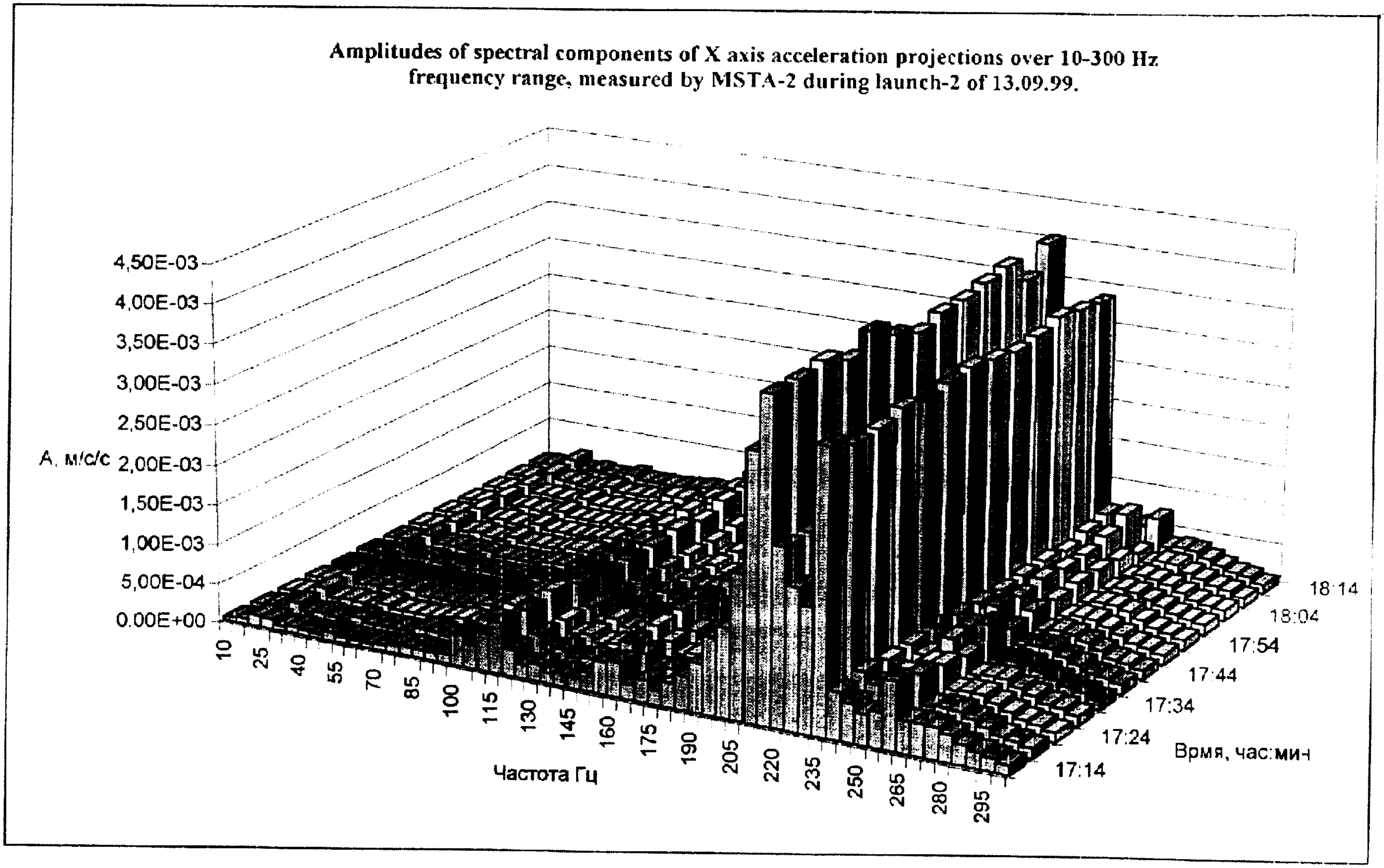

Amplitudes of spectral components of X axis acceleration projections over 10-300 Hz frequency range, measured by MSTA-2 during launch-2 of 13.09.99.
A, м/с/с
4,50E-03
4,00E-03
3,50E-03
3,00E-03
2,50E-03
2,00E-03
1,50E-03
1,00E-03
5,00E-04
0,00E+00
10
25
40
55
70
85
100
115
130
145
160
175
190
205
220
235
250
265
280
295
Частота Гц
17:14
17:24
17:34
17:44
17:54
18:04
18:14
Время, час:мин

Fig. 4

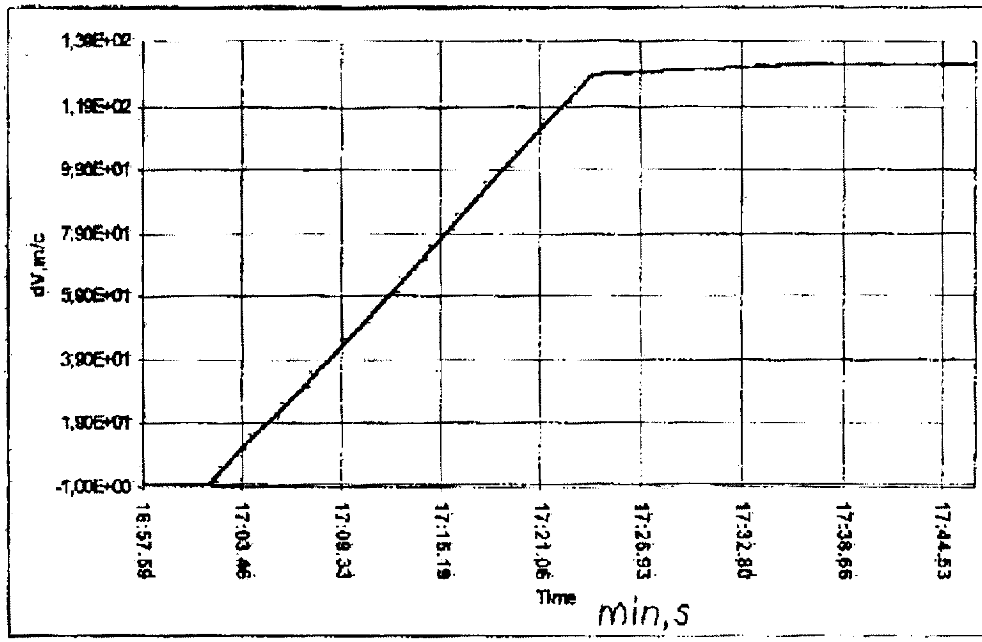


Fig. 5 (X axis)

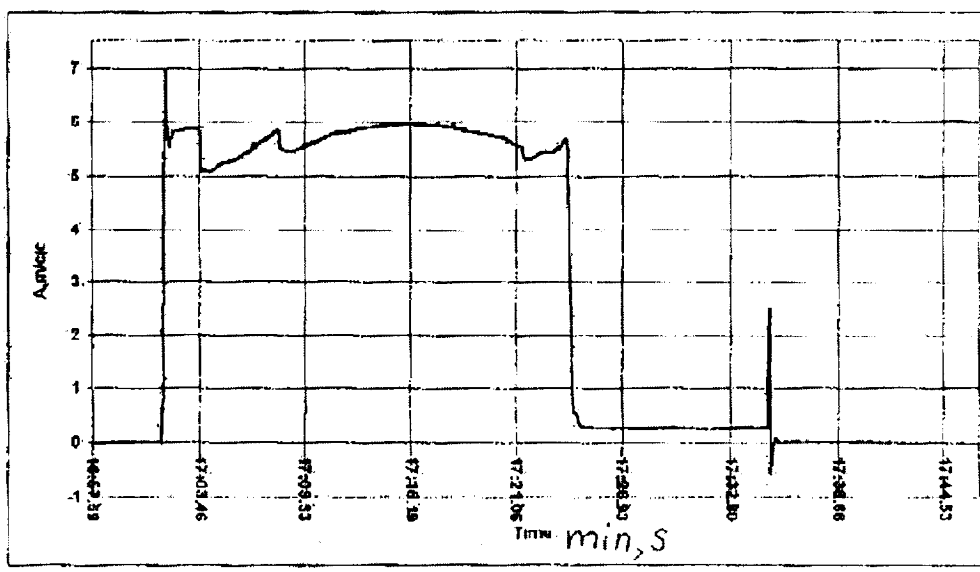


Fig. 6 (X axis)

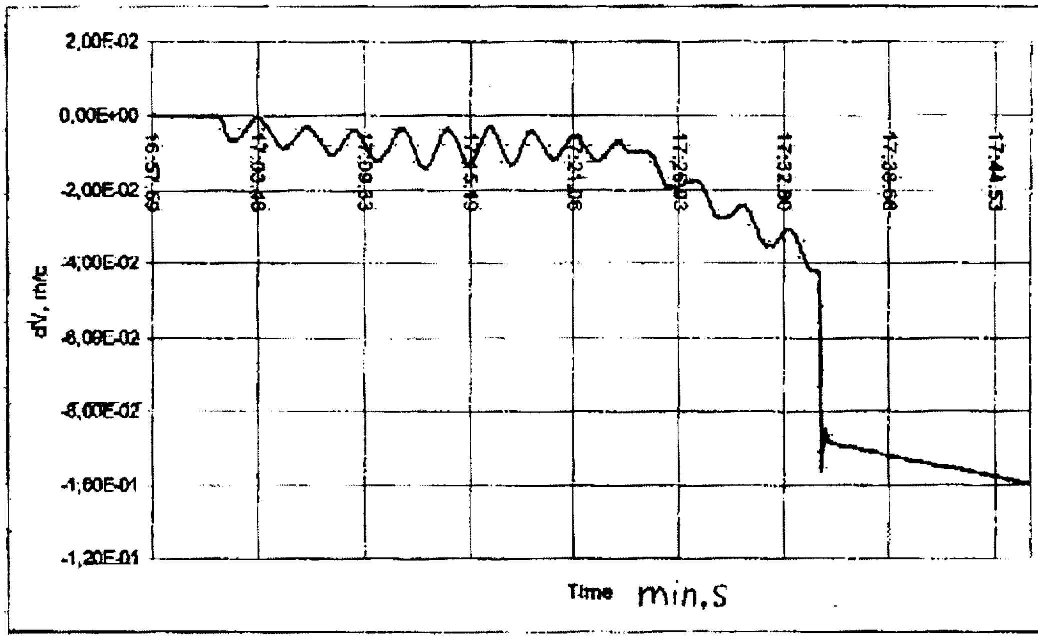


Fig. 7 (Y axis)

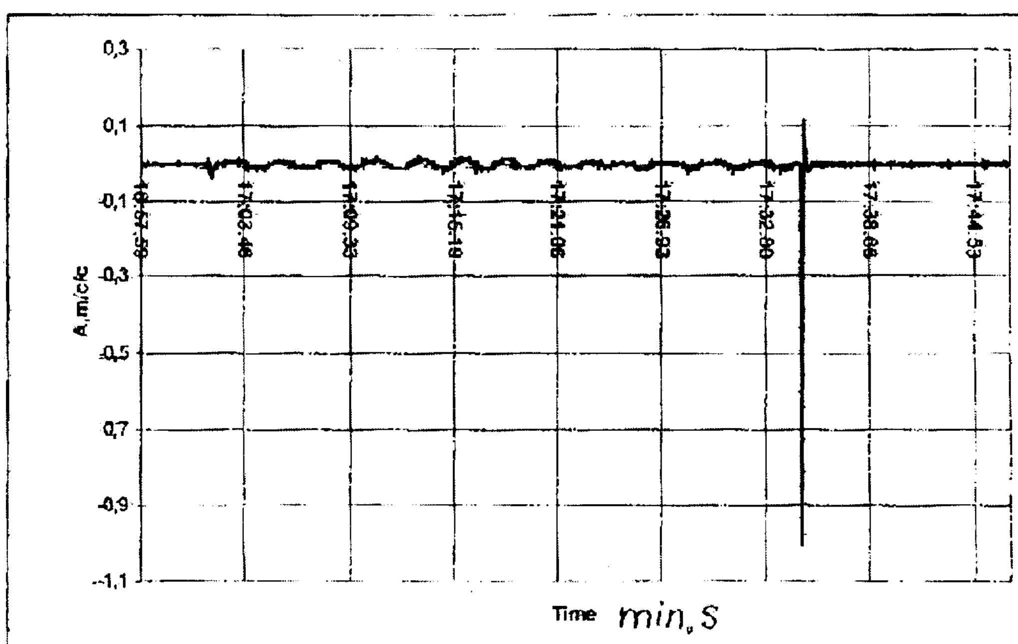


Fig. 8 (Y axis)

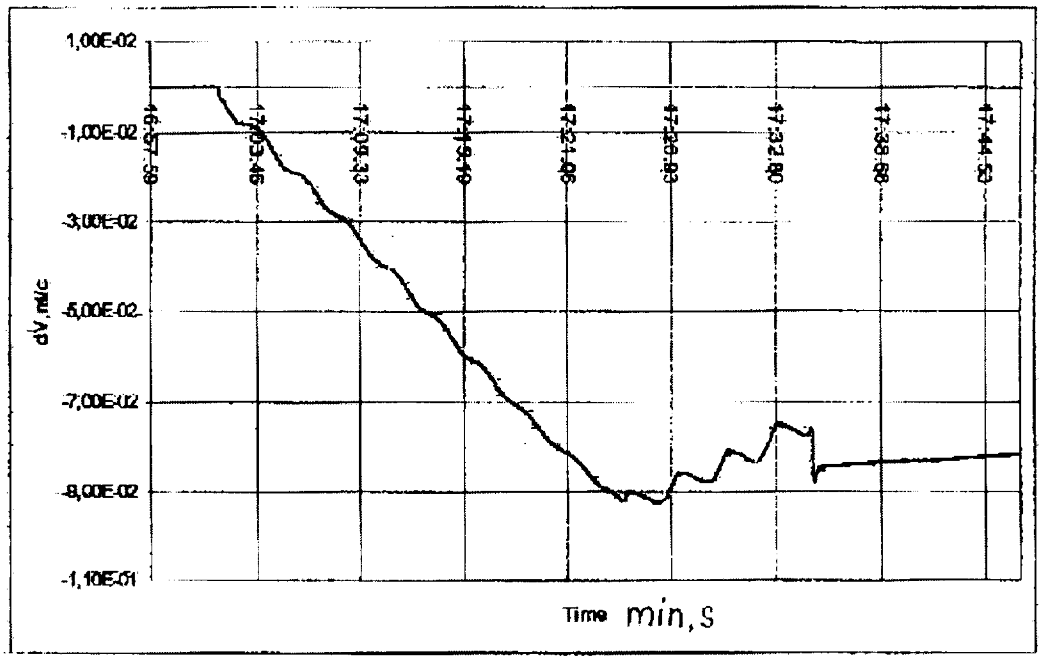


Fig. 9 (Z axis)

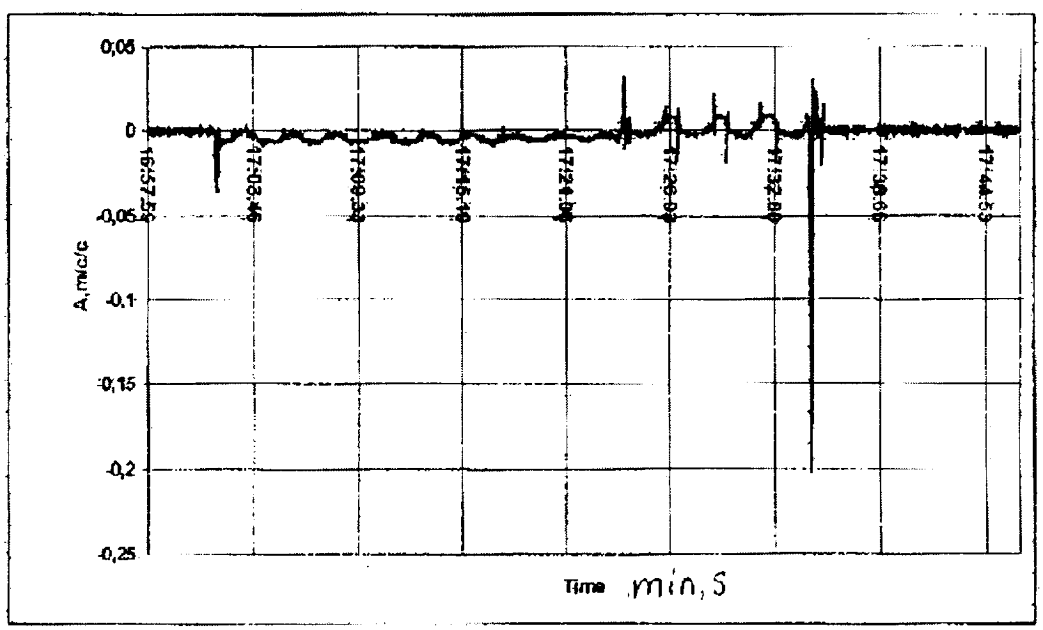


Fig. 10 (Z axis)

Fig. 7, 8 and Fig. 9, 10 – respectively velocity and acceleration of the platform and the re-entry capsule in the directions perpendicular to the orbital velocity (axes Y and Z of the accelerometer).

Next "Photon" flight named as "Photon-M" №1 is planned for the second half of 2002. It will be totally modified including replacement of practically all major on-board systems. The purpose of the modification is improvement of technical performances mainly augmentation of power for experimental gear, increase of payload mass, further decrease of microgravity in quasistatic and vibration ranges.

20010019758

512588

20p

225/29

MGMG #19

Paper Number: 25

PIMS real-time data reception and environment characterization

Kevin McPherson
NASA Glenn Research Center
Cleveland, Ohio

Kenneth Hrovat
ZIN Technologies
Brook Park, Ohio

The methodology and system concepts developed by the PI Microgravity Services (PIMS) project to process real-time ISS microgravity acceleration data will be presented. The characterization of these data and analyses into information meaningful to microgravity scientists will also be described.

Principal Investigator Microgravity Services Role In ISS Acceleration Data Distribution

Principal Investigator Microgravity Services Role In ISS Acceleration Data Distribution

Kevin M. McPherson
NASA Glenn Research Center
PIMS Project Manager
Phone: 1 216 433 6182
Electronic Mail: Kevin.McPherson@grc.nasa.gov

Principal Investigator Microgravity Services Role In ISS Acceleration Data Distribution

Principal Investigator Microgravity Services Project

- Support the Microgravity Measurement and Analysis Project (MMAP) at the NASA Glenn Research Center
- Process, analyze and interpret accelerometer data to characterize the microgravity environment of Earth-orbiting laboratories for the microgravity Principal Investigators (PI)
- Maintain archive of acceleration data from various microgravity platforms including ISS, Mir, Space Shuttle, KC-135, and sounding rockets

MGMG #19 July, 2000 / Page 2

Principal Investigator Microgravity Services Role In ISS Acceleration Data Distribution

Principal Investigator Microgravity Services Project

- PIMS performs the project scientist role for the acceleration measurement systems
  - PIMS works with the science experiment Principal Investigators, project scientists, and other program participants to assist in the understanding and use of the acceleration data and information
  - PIMS products include general and specific analysis, vehicle characterization, and mission summary reports
  - PIMS conducts the Microgravity Measurements Group (MGMG) meetings to foster interchange of data and information within the microgravity environment community and to the microgravity science community
  - PIMS conducts the Microgravity Environment and Interpretation Tutorial (MEIT) to convey significant features of the microgravity acceleration environment to the microgravity Principal Investigator teams and other interested parties

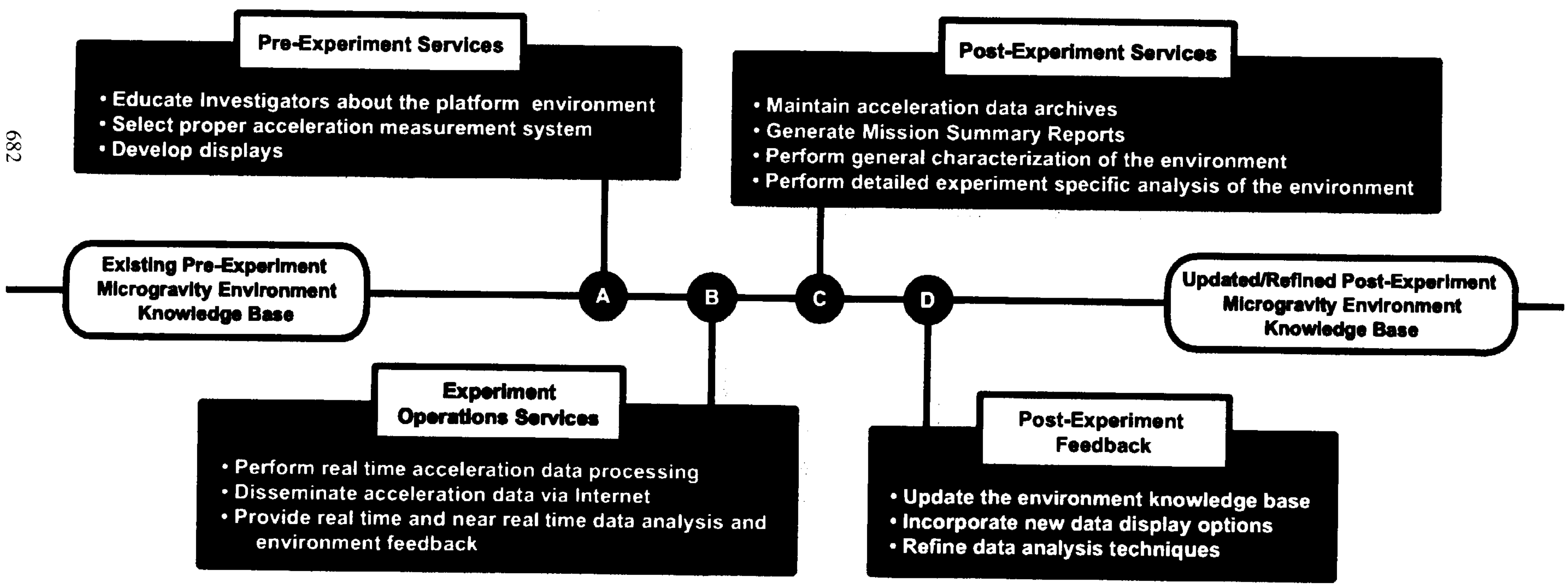
MGMG #19 July, 2000 / Page 3

PIMS Team

NAME	TITLE
Kevin McPherson	Project Manager
Dick DeLombard	Acceleration Discipline Scientist
Kenol Jules	Project Scientist
Ted Wright	Software Engineer
Nissim Lugasy	Software Engineer
Gene Liberman	Software Engineer
Tim Reckart	Web Developer
Eric Kelly	Data Analyst
Ken Hrovat	Data Analyst

Principal Investigator Microgravity Services Role In ISS Acceleration Data Distribution

PIMS Functions During Experiment Life Cycle



MGMG #19 July, 2000 / Page 4

Principal Investigator Microgravity Services Role In ISS Acceleration Data Distribution

PIMS World Wide Web Links

Acceleration Measurement WWW links

- Microgravity Science Division at NASA Glenn Research Center
  - http://microgravity.grc.nasa.gov
- NASA Glenn Acceleration Measurement Program
  - http://microgravity.grc.nasa.gov/MSD/MSD_htmls/accel_meas.html
- Principal Investigator Microgravity Services Home Page
  - http://microgravity.grc.nasa.gov/MSD/MSD_htmls/PIMS.html

Microgravity Environment References

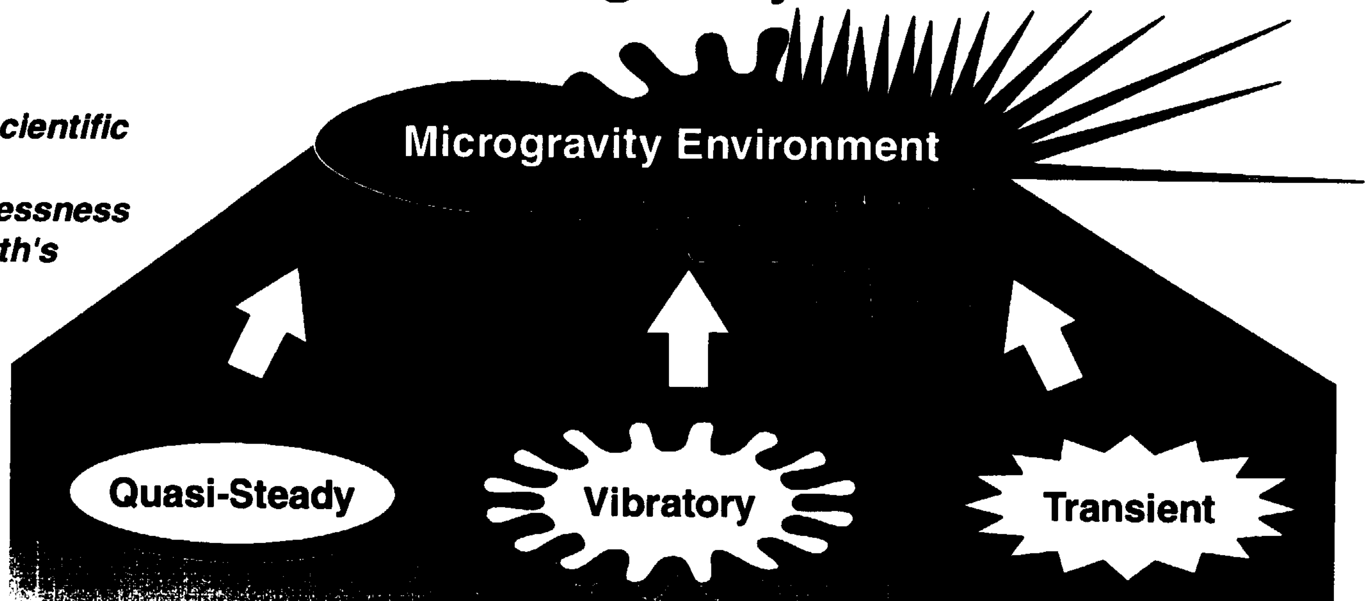
- Microgravity Environment Description Handbook TM-107486
  - Compilation of major microgravity environment disturbances, their sources and effects as measured on the Shuttle Orbiters and the Mir Space Station
  - http://www.grc.nasa.gov/WWW/MMAP/PIMS/HTMLS/Micro-descpt.html
- Acceleration Data Analysis and Presentation Techniques TM-113173
  - Detailed description of acceleration data analysis techniques
  - http:// www.grc.nasa.gov/WWW/MMAP/PIMS/HTMLS/adapt.html
- Mission Summary Reports
  - Mission specific characterizations for various Shuttle and Mir missions
  - http:// www.grc.nasa.gov/WWW/MMAP/PIMS/HTMLS/reportlist.html

MGMG #19 July, 2000 / Page 5

Principal Investigator Microgravity Services Role In ISS Acceleration Data Distribution

Components of the Microgravity Environment

Microgravity is:
- *a general label for scientific investigations that exploit near-weightlessness*
- *one-millionth of Earth's normal gravity*
- *a reduced gravity environment*



Component	Quasi-Steady	Vibratory	Transient
Frequency	$0 \leq f < 0.01$ Hz	$0.01 \leq f \leq 300$ Hz	[illegible]
Magnitude	μg's (or less) peak	tens to thousands μg_{RMS}	tens of mg's peak
Primary Sources	**gravity gradient & rotational effects:** not at center of mass **drag:** function of altitude, attitude, day/night, etc. **vehicle:** venting water or air	**equipment:** pumps, fans, centrifuges, compressors, etc. **crew:** ergometer or treadmill exercise **vehicle:** structural modes	**vehicle:** thrusters, dockings **crew:** pushoffs & landings, drawer/door closings, experiment setup **equipment:** machinery startup

MGMG #19 July, 2000 / Page 6

Operational Philosophy

- Operations are divided into three sections:
  - 1) Real-time operations
  - 2) Near real-time operations
  - 3) Offline operations
    - general characterization and specialized analysis
- Acceleration measurement using SAMS-II and MAMS planned for the duration of ISS operations beginning with Flight 6A operations
- Potential for nearly continuous operations to characterize the environment
  - includes measurement of the environment, where possible, outside of "microgravity mode"
- AOS/LOS profiles call for 30 - 60 percent AOS coverage
  - requires the ability to deal with AOS and LOS data streams

Principal Investigator Microgravity Services Role In ISS Acceleration Data Distribution

Operational Philosophy

- Flight 6A operational configuration calls for 5 SAMS-II Sensor Enclosures (SE), MAMS MESA, and MAMS HiRAP
  - not all sensors will be active all the time resulting in a variety of acceleration measurement profiles
- PIMS has developed a core set of techniques for processing and displaying the acceleration data
  - Based on real-time and offline experience gained from SAMS and OARE data during Space Shuttle and Mir operations
  - Customized processing or displays as required by the microgravity user community
- Microgravity acceleration data will be available to Principal Investigators
  - Working with international partners on establishing a universal file format standard for acceleration data

Principal Investigator Microgravity Services Role In ISS Acceleration Data Distribution

PIMS Data Analysis Techniques

Display Format	Regime(s)	Notes
Acceleration versus Time	Transient, Quasi-Steady, Vibratory	• precise accounting of measured data with respect to time; best temporal resolution
Interval Min/Max Acceleration versus Time	Vibratory, Quasi-Steady	• displays upper and lower bounds of peak-to-peak excursions of measured data • good display approximation for time histories on output devices with resolution insufficient to display all data in time frame of interest
Interval Average Acceleration versus Time	Vibratory, Quasi-Steady	• provides a measure of net acceleration of duration greater than or equal to interval parameter
Interval RMS Acceleration versus Time	Vibratory	• provides a measure of peak amplitude
Trimmed Mean Filtered Acceleration versus Time	Quasi-Steady	• removes infrequent, large amplitude outlier data
Quasi-Steady Mapped Acceleration versus Time	Quasi-Steady	• use rigid body assumption and vehicle rates and angles to compute acceleration at any point in the vehicle
Quasi-Steady Three-Dimensional Histogram (QTH)	Quasi-Steady	• summarize acceleration magnitude and direction for a long period of time • indication of acceleration "center-of-time" via projections onto three orthogonal planes

MGMG #19 July, 2000 / Page 11

PIMS Data Analysis Techniques

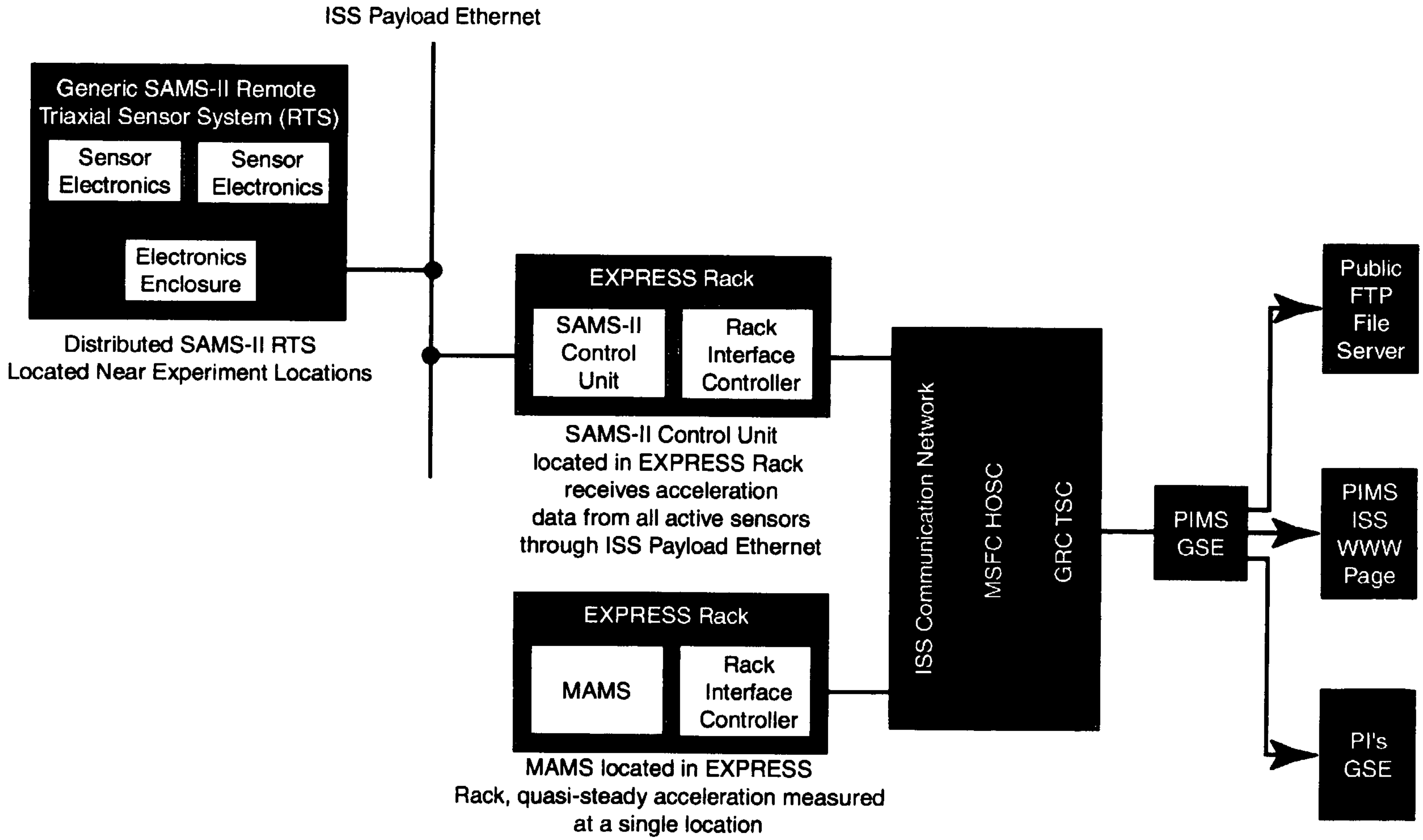
Display Format	Regime(s)	Notes
Power Spectral Density (PSD) versus Frequency	Vibratory	• displays distribution of power with respect to frequency
Spectrogram (PSD versus Frequency versus Time)	Vibratory	• displays power spectral density variations with time • identify structure and boundaries in time and frequency
Cumulative RMS Acceleration versus Frequency	Vibratory	• quantifies RMS contribution at and below a given frequency
Frequency Band(s) RMS Acceleration versus Time	Vibratory	• quantify RMS contribution over selected frequency band(s) as a function of time
RMS Acceleration versus One-Third Frequency Bands	Vibratory	• quantify RMS contribution over proportional frequency bands • compare measured data to ISS vibratory requirements
Principal Component Spectral Analysis (PCSA)	Vibratory	• summarize magnitude and frequency excursions for key spectral contributors over a long period of time • results typically have finer frequency resolution and high PSD magnitude resolution relative to a spectrogram at the expense of poor temporal resolution

Real-Time Operations

- Crux of real-time operations involves receiving, processing, and displaying microgravity acceleration data via the WWW
- Acceleration data displays via the WWW
  - PIMS displays are updated in real-time
  - Electronics snapshots are routed to the PIMS WWW page
  - Interested Principal Investigators can view the environment by accessing the PIMS WWW page
- Example real-time plots
  - Figure 1 USMP-4 (STS-87) IDGE Experiment Turn Off
  - Figure 2 USMP-4 (STS-87) Cabin De-Pressurization for EVA
  - Figure 3 LMS (STS-78) Nominal Microgravity Environment

Principal Investigator Microgravity Services Role In ISS Acceleration Data Distribution

PIMS ISS Acceleration Data Flow



MGMG #19 July, 2000 / Page 14

Principal Investigator Microgravity Services Role In ISS Acceleration Data Distribution

Near Real-Time Operations

- **Two primary functions performed**
  - **Merge AOS and LOS data streams**
  - **Generate processed (t,x,y,z) data files**
    - store the data in a universal storage format
- **Universal file format standard details**
  - **Develop a standard file format for ISS acceleration data from any ISS acceleration measurement system**
  - **Simplify access to acceleration data for Principal Investigators**
  - **Store ancillary data with acceleration data in a single file**
    - ancillary data describes the conditions and circumstances under which the acceleration data were obtained
    - current ancillary data parameters include: t-zero, t-end, sampling rate, cutoff frequency, head ID, gain, ISS CM, station configuration, location, orientation, coordinate system, bias coefficients, scale factor, and Data Quality Measure (DQM)

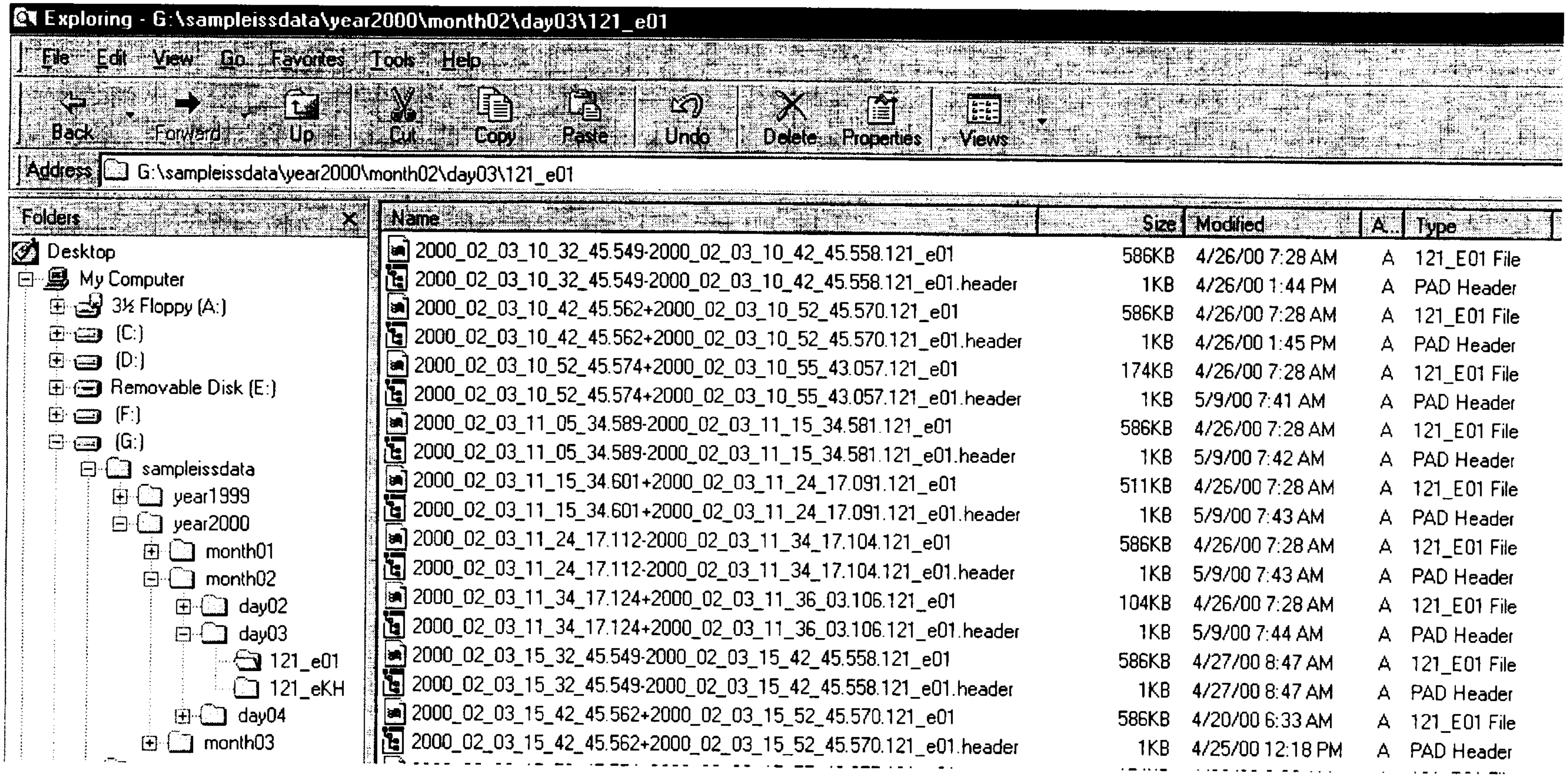
Principal Investigator Microgravity Services Role In ISS Acceleration Data Distribution

Offline Operations

- Primary function is to allow access to acceleration data for non-time-critical processing
  - In general, allows a more detailed analysis of the measured microgravity environment
  - Capable of processing and analyzing a long period of data
  - Overall access to acceleration data greatly simplified by a universal storage format
- PIMS WWW page offline functions
  - Provide the capability to request plotted data or data files
  - Provide the capability for submitting an electronic request for data processing
  - Provide means for anonymous FTP access to the processed acceleration data files

MGMG #19 July, 2000 / Page 16

Data Archive



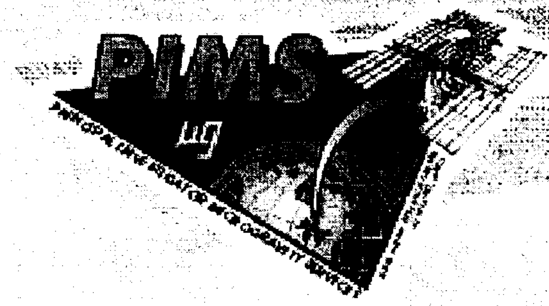
Principal Investigator Microgravity Services Role In ISS Acceleration Data Distribution

Summary

- PIMS will receive, process, and store acceleration data for SAMS-II and MAMS data starting with flight 6A operations
- A universal storage format will be employed for data storage
  - simplify access to acceleration data
  - standardize formats for data storage to maximize access to all existing acceleration data by international partners
- Real-time data plots of the various available accelerometers will be available via the PIMS WWW page
- Offline access to plotted data and analysis capabilities available through PIMS and the PIMS WWW page
- General and specialized characterization of the ISS microgravity environment

[3] Moskowitz, M., Hrovat, K., Tschen, P., McPherson, K., Nati, M. & Reckart, T. (1998) Summary Report of Mission Acceleration Measurements for MSL-1. NASA Technical Memorandum 1998-206979.

[4] Rogers, M. J. B., Hrovat, K., McPherson, K., & Reckart, T. (1999) Summary Report of Mission Acceleration Measurements



PIMS Contacts

PIMS Project Manager
Kevin M. McPherson
NASA Glenn Research Center
21000 Brookpark Rd.
Cleveland, OH 44135
Phone: (216) 433-6182
Fax: (216) 433-8660
Email:
pims@grc.nasa.gov

Acceleration Measurement Program Manager
David R. Francisco
NASA Glenn Research Center
21000 Brookpark Rd.
Cleveland, OH 44135
Phone: (216) 433-5285
Fax: (216) 433-8660
Email:
David.R.Francisco@grc.nasa.gov

Acceleration Discipline Scientist
Richard DeLombard
NASA Glenn Research Center
21000 Brookpark Rd.
Cleveland, OH 44135
Phone: (216) 433-5285
Fax: (216) 433-8660
Email:
richard.delombard@grc.nasa.gov

5-6/29

4759

512589
44P

Paper Number: 26

ISS Microgravity Environment Monitoring System (MEMS) - Part I: system design

Kenol Jules
NASA Glenn Research Center
Cleveland, Ohio

Paul P. Lin
Cleveland State University
Cleveland, Ohio

The Principal Investigator Microgravity Services project at the NASA Glenn Research center supports Principal Investigators of the microgravity science community as they evaluate the effects of acceleration on their experiments. The Principal Investigator Microgravity Services' primary responsibility is to support NASA sponsored investigators in the area of acceleration data analysis, interpretation and the monitoring of the microgravity environment on-board various carriers. The microgravity environment is a rich and very complex dynamic one. It is subject to quasi-steady accelerations, higher frequency acceleration, and transient disturbances.

With the advent of the International Space Station operation, a significant amount of data is expected to be downlinked and processed for both the space station microgravity environment characterization (verification) and scientific experiments. Therefore, to help principal investigator teams monitor the microgravity environment on-board the International Space Station in order to avoid negative impact on their experiment, when possible, the NASA Glenn Principal Investigator Microgravity Services project is currently developing an artificial intelligence monitoring system, which will notify the principal investigator teams in near real time of any change in the microgravity environment susceptible to affect their experiments.

The main objective of this artificial intelligence monitoring system is to help the principal investigator teams, in near real time, identify the primary vibratory disturbance sources that are active at any moment in time on-board the International Space Station, which might impact the microgravity environment their experiments are

exposed to. The soft computing techniques, which are being used, consist of an adaptive pattern classification, which is a hybrid of Kohonen's Self-Organizing Feature Mapping and Learning Vector Quantization, neural networks, and fuzzy logic. This monitoring system will allow any principal investigator team, at any location and any time, to see the current acceleration level on-board of the Space Station via the World Wide Web. From the Principal Investigator Microgravity Services' web site, the principal investigator teams will see in near real time which event (s) is/are on, such as crew activities, pumps, fans, centrifuges, compressor, crew exercise, platform structural exciting modes, etc., and decide whether or not to run their experiments based on the g-level associated with a specific event. In addition, they will have access via the web to a graphical display, which shows the status of all the vibratory disturbance sources with their degree of confidence as well as their impact on the microgravity environment. This artificial intelligence monitoring system will be synchronized with the International Space Station's on-board clock so that a log of events is recorded for the principal investigator teams future use. This monitoring system is focused primarily on detecting the vibratory disturbance sources, but could be used as well to detect some of the transient disturbance sources, depending on how long such events last. The system has enough built-in smartness to detect both known and unknown vibratory disturbance sources.

ISS Microgravity Environment Monitoring System (MEMS)

ISS Microgravity Environment Monitoring System (MEMS)

Part I : System Design

Kenol Jules
PIMS Project Scientist
NASA Glenn Research Center, Ohio

Paul P. Lin
Cleveland State University, Ohio

19th International MicroGravity Measurements Group Meeting
Cleveland, Ohio --- July 11 - 13, 2000

CONTENT

- Principal Investigator Microgravity Services (PIMS) -- Overview
- Problem Identification / Definition
- Proposed Solution
- Microgravity Environment Brief Description
- Soft Computing Techniques Description
- System Design Structure
- System Operative Modes
- Web-based Visual Display
- Discussion and Conclusion

Principal Investigator Microgravity Services (PIMS)

PIMS performs the project scientist role for the accelerometer instruments:

- PIMS works with the science experiment Principal Investigators, project scientists, and other program participants to assist in the understanding and use of the acceleration data and information
- PIMS products include general and specific analyses, vehicle characterization, and mission summary reports
- PIMS conducts the Microgravity Measurements Group (MGMG) meetings to foster interchange of data and information within the microgravity environment community and to the microgravity science community
- PIMS conducts the Microgravity Environment & Interpretation Tutorial (MEIT) to educate PI teams about the effects of the environment on their experiments and vice-versa, and also, how to use and interpret the acceleration data and analysis.

ISS Microgravity Environment Monitoring System (MEMS)

Microgravity Environment Interpretation Tutorial (MEIT)

The objectives of the NASA Glenn MEIT tutorial training course are:

1. Educate both Project Scientists (PS) and Principal Investigator (PI) about the impact the microgravity environment will have on their experiments.
2. Expose the PSs and PIs to the different methods that can be used to assess and quantify the microgravity impact so that it can be taken into account during data analysis and interpretation.
3. Make the attendees aware of the many services PIMS project offers to PSs and PIs.

The following topics are covered:

1. Components of the microgravity environment of orbiting spacecraft
2. Known impacts of the microgravity environment on experiments
3. Analysis of accelerometer data
4. Different microgravity platform signatures
5. Predicting residual acceleration effects on space experiments.

ISS Microgravity Environment Monitoring System (MEMS)

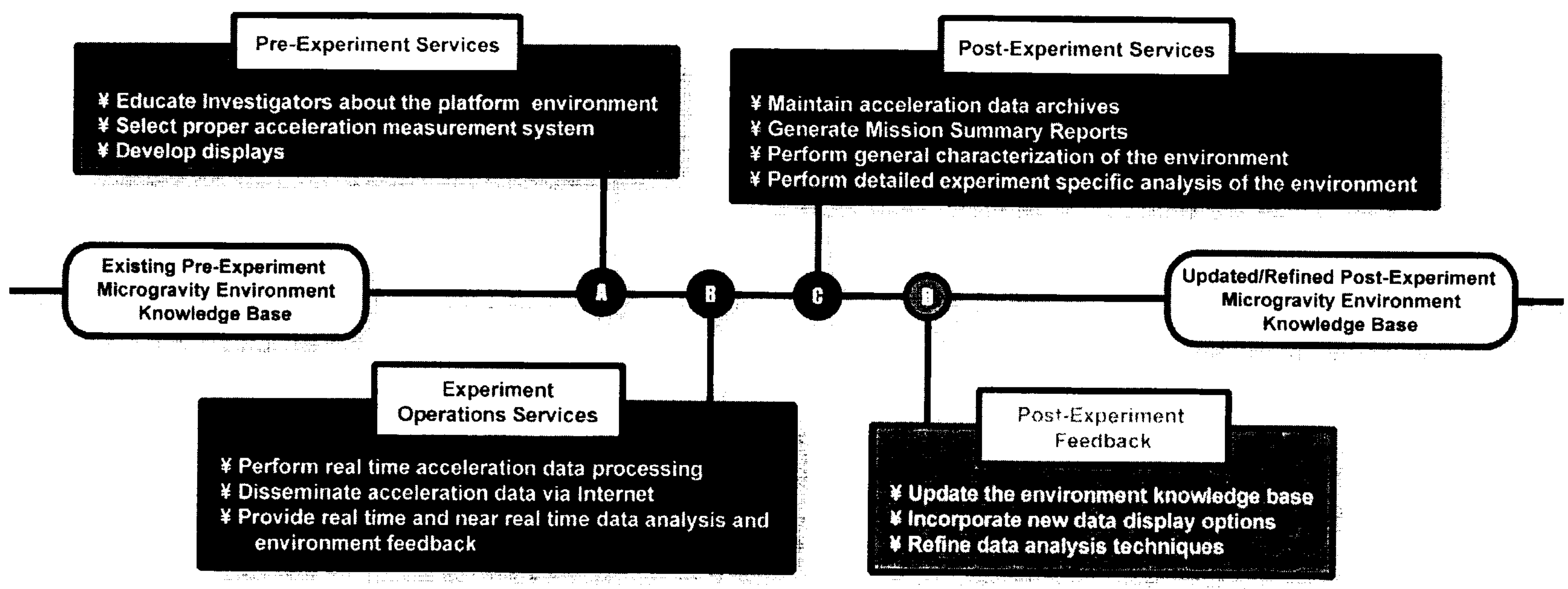
Principal Investigator Microgravity Services (PIMS)

Support NASA's Microgravity Research Program Principal Investigators (PIs) by providing acceleration data processing, analysis, and interpretation for a variety of reduced gravity carriers such as:

- Space Shuttle
- Parabolic Aircraft (KC-135)
- Sounding Rockets
- Drop Towers
- Mir
- ISS
- Ground Testing

ISS Microgravity Environment Monitoring System (MEMS)

PIMS Functions During Experiment Life Cycle



07/13/2000 NASA Gleen Research Center, Ohio 19th MGMG / Ohio / Page7

ISS Microgravity Environment Monitoring System (MEMS)

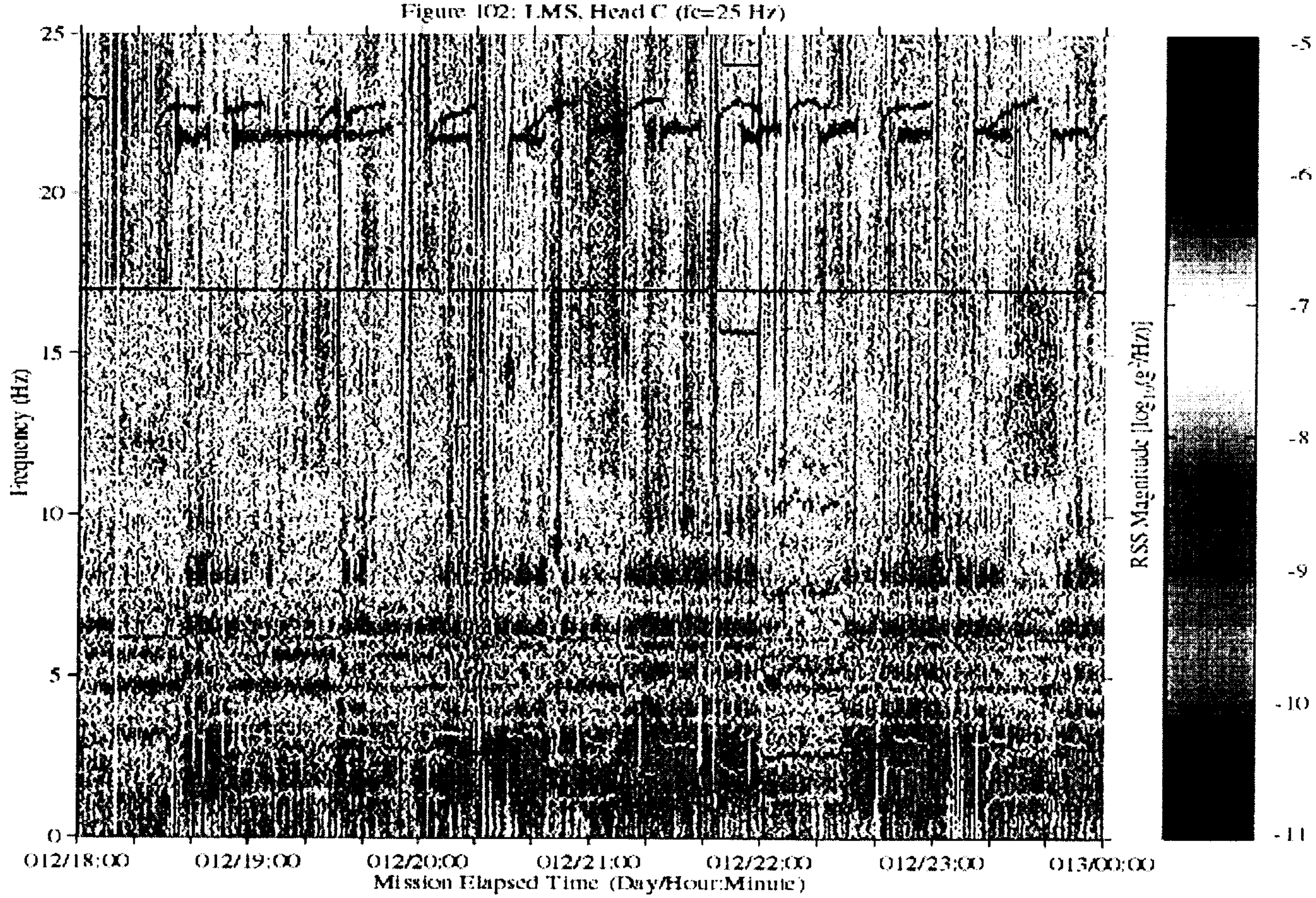
CONTENT

- Principal Investigator Microgravity Services (PIMS) -- Overview
- Problem Identification / Definition
- Proposed Solution
- Microgravity Environment Brief Description
- Soft Computing Techniques Description
- System Design Structure
- System Operative Modes
- Web-based Visual Display
- Discussion and Conclusion

ISS Microgravity Environment Monitoring System (MEMS)

PROBLEM IDENTIFICATION

Figure 102: LMS, Head C (fc=25 Hz)



ISS Microgravity Environment Monitoring System (MEMS)

PROBLEM IDENTIFICATION / DEFINITION

Identify, in near real time, the active vibratory disturbance sources, at time, on-board the ISS from the acceleration data, which are being downlinked from the station. The followings must be taken into account:

- Multiple Sensors Throughout The Science Module
- Multiple Science Racks Throughout The Science Module
- Various Vibratory Disturbance Sources on the ISS
- Sensors with Selectable Filters / Sampling rates
- System Must Classify All Known Events in "Real Time"
- System Must Identify Unknown Events As Well

Once every thing is taking into account, the problem that needs to be solved becomes a rather very complex and difficult one!

ISS Microgravity Environment Monitoring System (MEMS)

CONTENT

- Principal Investigator Microgravity Services (PIMS) -- Overview
- Problem Identification / Definition
- Proposed Solution
- Microgravity Environment Brief Description
- Soft Computing Techniques Description
- System Design Structure
- System Operative Modes
- Web-based Visual Display
- Discussion and Conclusion

ISS Microgravity Environment Monitoring System (MEMS)

PROPOSED SOLUTION

Developed an artificial intelligence monitoring system, which will show the PIs team, in near real time, any change in the microgravity environment that might affect their experiments. The system will extract, analyze, and interpret the most salient features of the microgravity environment on-board the ISS. The monitoring system will do mainly the followings:

- Detect the current vibratory events on-board the ISS in near real time
- Classify each known event and assess their relative impact on the environment
- Identify unknown events, which require characterization

NOTE: The main focus of this monitoring system is the vibratory regime, but some transient events can be detected, depending on their duration.

ISS Microgravity Environment Monitoring System (MEMS)

CONTENT

- Principal Investigator Microgravity Services (PIMS) -- Overview
- Problem Identification / Definition
- Proposed Solution
- Microgravity Environment Brief Description
- Soft Computing Techniques Description
- System Design Structure
- System Operative Modes
- Web-based Visual Display
- Discussion and Conclusion

ISS Microgravity Environment Monitoring System (MEMS)

MICROGRAVITY ENVIRONMENT DESCRIPTION

The microgravity acceleration environment of an orbiting spacecraft in a low earth orbit is a very complex phenomenon. Many factors contribute to form the overall microgravity environment. In general, it can be considered as made up of the following three components:

<u>QUASI-STEADY</u>: is composed of those accelerations that vary over long periods of time, typically longer than a minute.

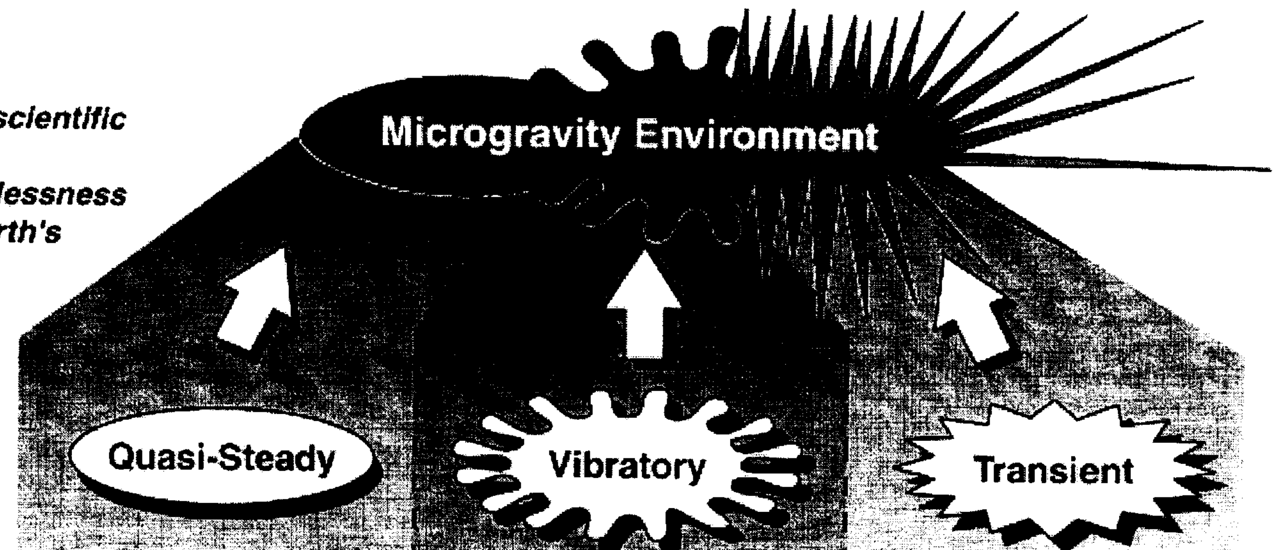
<u>VIBRATORY</u>: is composed of those accelerations that are harmonic and periodic in nature with a characteristic frequency.

<u>TRANSIENT</u>: is composed of those accelerations that last for a short period period of time, and are non-repetitive.

ISS Microgravity Environment Monitoring System (MEMS)

Components of the Microgravity Environment

Microgravity is:
- *a general label for scientific investigations that exploit near-weightlessness*
- *one-millionth of Earth's normal gravity*
- *a reduced gravity environment*



Component	Quasi-Steady	Vibratory	Transient
Frequency	$0 \leq f < 0.01$ Hz	$0.01 \leq f \leq 300$ Hz	broadband
Magnitude	μg's (or less) peak	tens to thousands μg_{RMS}	tens of mg's peak
Primary Sources	**gravity gradient & rotational effects:** not at center of mass **drag:** function of altitude, attitude, day/night, etc. **vehicle:** venting water or air	**equipment:** pumps, fans, centrifuges, compressors, etc. **crew:** ergometer or treadmill exercise **vehicle:** structural modes	**vehicle:** thrusters, dockings **crew:** pushoffs & landings, drawer/door closings, experiment setup **equipment:** machinery startup

ISS Microgravity Environment Monitoring System (MEMS)

CONTENT

- Principal Investigator Microgravity Services (PIMS) -- Overview
- Problem Identification / Definition
- Proposed Solution
- Microgravity Environment Brief Description
- Soft Computing Techniques Description
- System Design Structure
- System Operative Modes
- Web-based Visual Display
- Discussion and Conclusion

ISS Microgravity Environment Monitoring System (MEMS)

SOFT COMPUTING TECHNIQUES

To solve the complex problem of identifying the known and unknown vibratory disturbance sources on-board the ISS in near real time, four different techniques are used:

- Kohonen's Self-Organizing Feature Map (SOFM)
- Learning Vector Quantization (LVQ)
- Back-Propagation Neural Network (BPNN)
- Fuzzy Logic

In pattern classification, the requirement is to classify the signal sets presented to an observer into a finite number of classes (patterns) such that the average probability of misclassification is minimized. Therefore, the issue of particular importance is to <u>delineate the class boundaries where decisions are made.</u>

ISS Microgravity Environment Monitoring System (MEMS)

NOMENCLATURE

NEURONS: The interconnected processing elements in an artificial neural network (also known as nodes)

CLUSTERS: The groups formed by similarity within a data set

CLASSES: The groups consisting of one or more clusters (at a level higher than clusters)

COMPETITIVE LEARNING: The neuron whose weight vector was closest to the input vector is updated to be even closer. All neurons in the same layer compete with each other, and the winner takes it all. This way, a competitive network learns to classify the input vectors presented.

ISS Microgravity Environment Monitoring System (MEMS)

SELF-ORGANIZING FEATURE MAP

- Self-Organizing Feature Map (SOFM) is a special class of artificial neural networks. The networks are based on competitive learning, that is the output neurons of the network compete among themselves to be activated or fired. The result is that only one output neuron, or one neuron per group, is on at any time. In the course of a competitive learning, the neurons become selectively tuned to various input patterns (vectors) or classes of input patterns.
- SOFM is characterized by the formation of a topological map of the input patterns, in which the spatial locations (i.e., coordinates) of the neurons in the lattice correspond to intrinsic features of the input patterns.
- SOFM algorithm provides an "approximate method" for computing vectors quantizer in an unsupervised manner. The approximation is specified by the synaptic weight vectors of the neurons in the feature map. The computation of the feature map can be regarded as the first of two stages for solving the pattern-classification problem since it is used mainly to visualize metric-topological relationships of input vectors.

ISS Microgravity Environment Monitoring System (MEMS)

SELF-ORGANIZING FEATURE MAP

SOFM Major Strength:

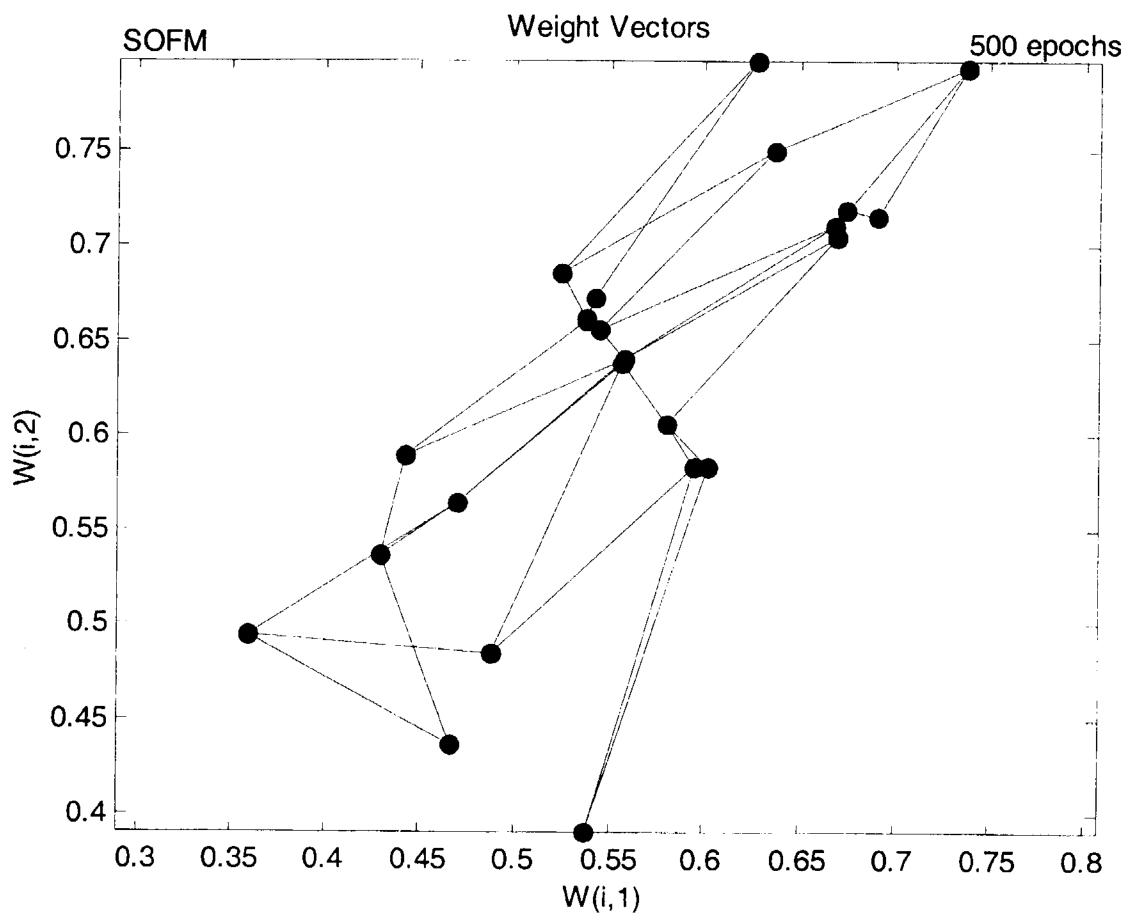
- Can group input vectors into several clusters
- Can generate a topological map of the input patterns

SOFM Major Weakness:

- Cannot group clusters into class
- Can misgroup input patterns to undesired clusters
- Cannot add new clusters when needed

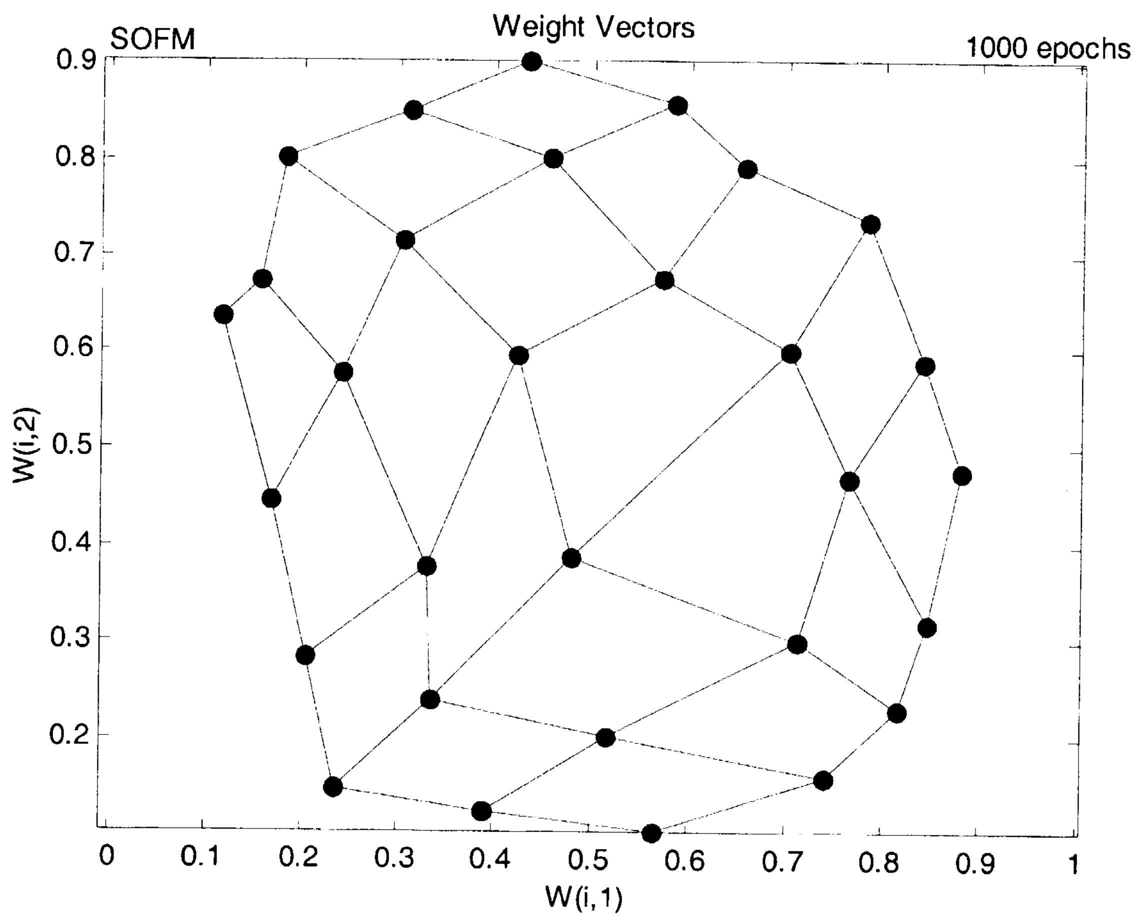
ISS Microgravity Environment Monitoring System (MEMS)

SOFM TOPOLOGICAL MAP



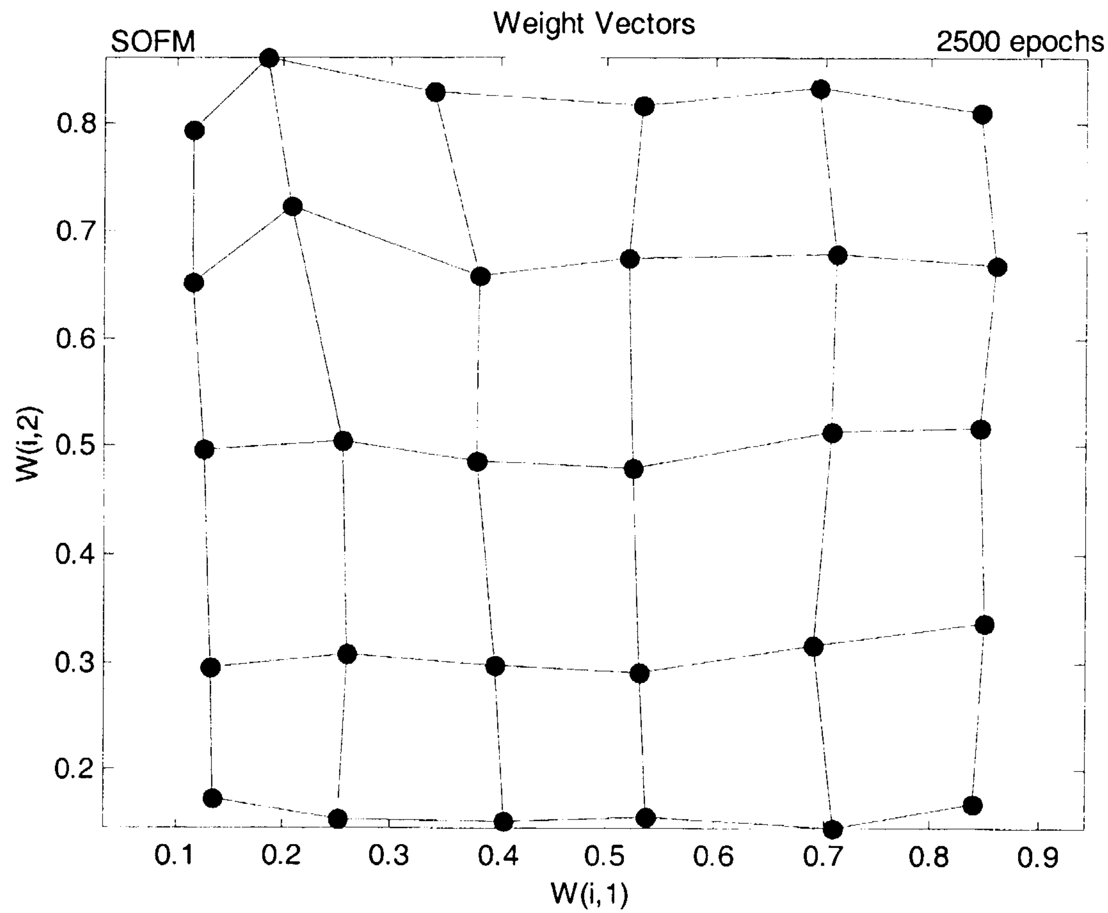
ISS Microgravity Environment Monitoring System (MEMS)

SOFM TOPOLOGICAL MAP



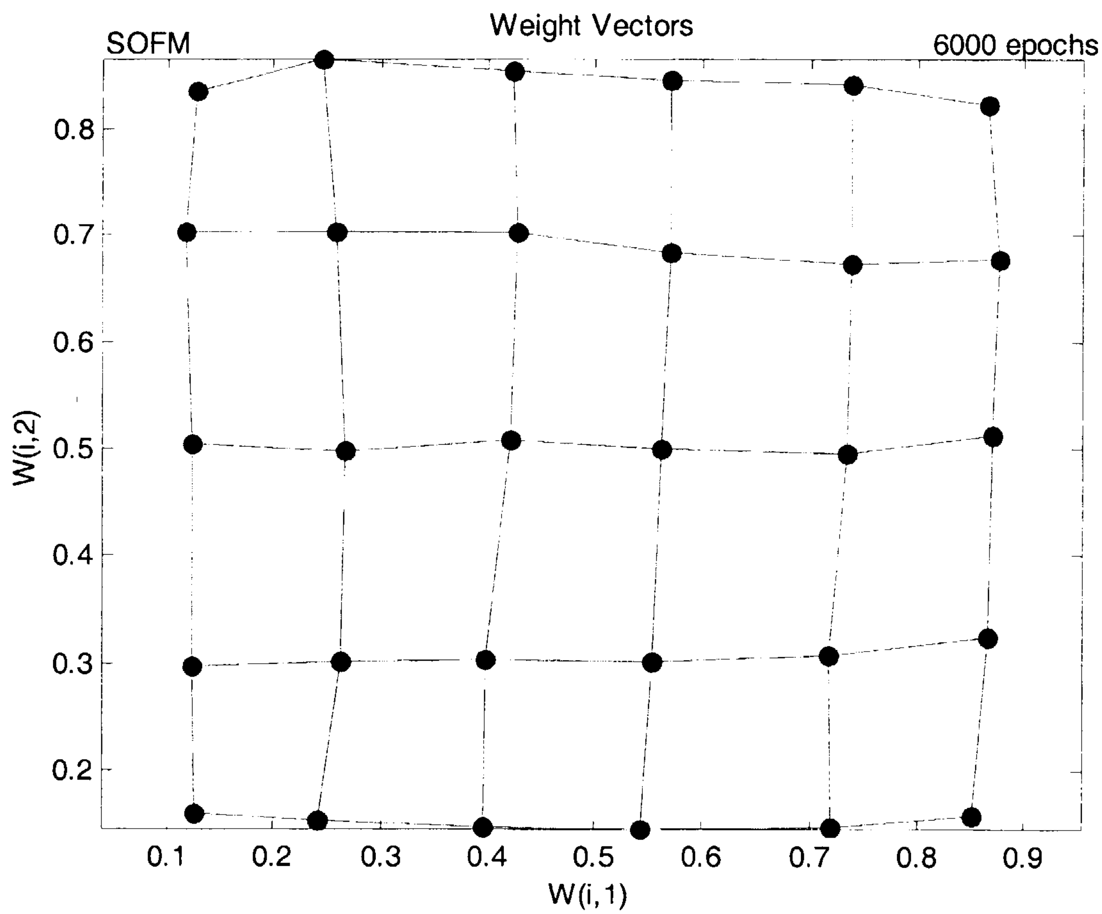
ISS Microgravity Environment Monitoring System (MEMS)

SOFM TOPOLOGICAL MAP



ISS Microgravity Environment Monitoring System (MEMS)

SOFM TOPOLOGICAL MAP



SELF-ORGANIZING FEATURE MAP

Summary of the SOFM Algorithm:

- Initialization: choose random values for the initial weight vectors
- Sampling : draw a sample x from the input distribution with a certain probability
- Similarity matching: find the best-matching (winning) neuron i(x) at time n, using the minimum-distance Euclidean criterion
- Updating: adjust the synaptic weight vectors of all neurons using an updating formula which takes into account* the learning-rate parameter and the neighborhood function centered around the winning neuron i(x).
- Continuation: continue with step 2 until no noticeable changes in the feature map are observed.

* The accuracy of the map depends on the number of iterations of the SOFM algorithm. The success of the map formation depends on how the learning rate parameter and the neighborhood function are selected.

LEARNING VECTOR QUANTIZATION

- Learning Vector Quantization (LVQ) is a supervised learning technique that uses class information in order to improve the quality of the classifier decision regions. Thus, it improves the classification performance of the SOFM and deals with the class-boundary decision-making processes.
- LVQ is a stochastic approximation algorithm, designed to minimize the possibility of misclassification since it learns to classify input vectors into the target classes specified by the user.

STRENGTH:

LVQ can be trained to identify classes made up of multiple unconnected regions.

WEAKNESS:

- Cannot find cluster centers by itself
- Cannot generate a topological map
- Unable to add new clusters when needed

ISS Microgravity Environment Monitoring System (MEMS)

FUZZY LOGIC

Fuzzy logic is a mathematical technique for understanding, and controlling specific manipulation of continuously variable truth-values. In more specific term, fuzzy logic is all about the relative importance of precision. Thus, fuzzy logic logic measures the truth of a given situation as a matter of degree.

Between the input and the output, there is a black box that does the work through the use of if-then rules, which embody the knowledge that governs the action of the system that is being described or modeled.

WHAT IS FUZZY LOGIC USED FOR HERE?

- To determine which sensor reading is more relevant to a specific experiment and disturbance sources
- To generate the degree of confidence as to what event is on for sure

ISS Microgravity Environment Monitoring System (MEMS)

NEURAL NETWORKS

Neural networks are systems that actually learn by doing. The network consists of many interconnected nodes, similar to neurons in the human brain. Each node assigns a value (known as weight) to the input from each of its counterparts. As these weight values are changed, the network can adjust the way it responds.

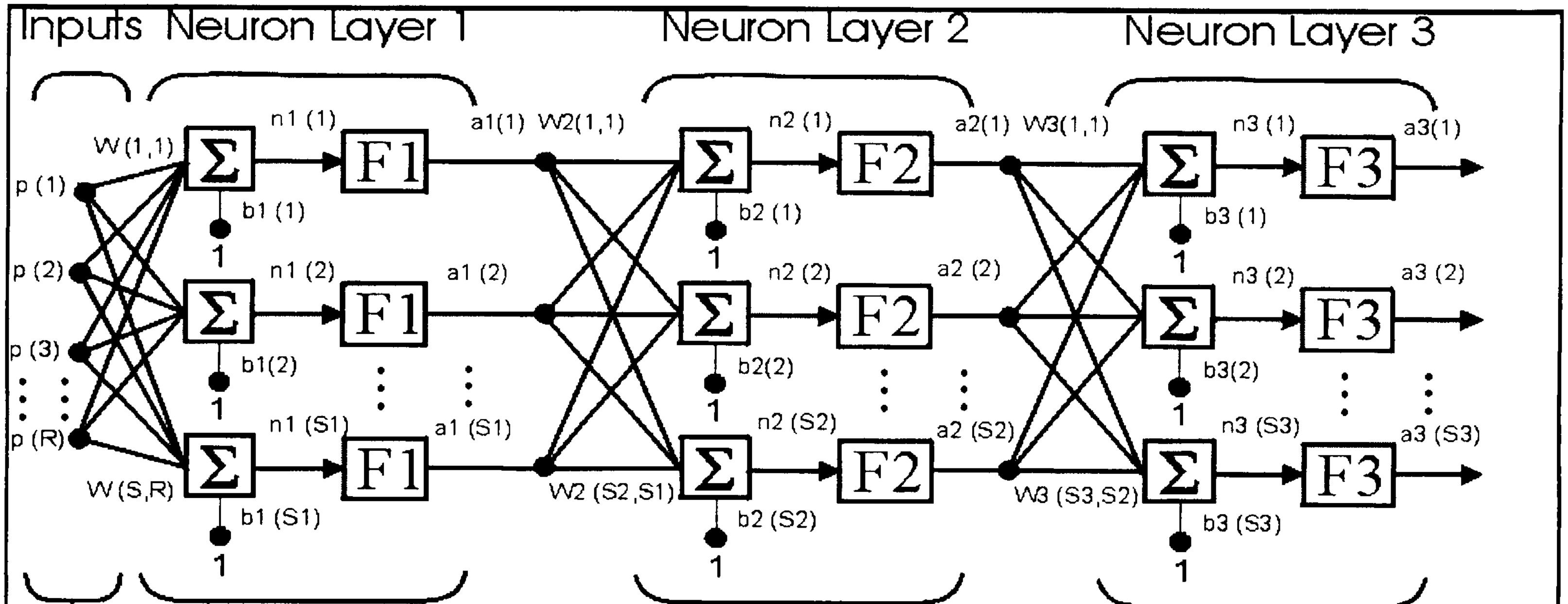
The power of the neural networks is not its elegance of any particular solution, but rather in the generality of the network to find its own solution to particular problems, given only examples of the desired behavior.

WHAT IS THE NEURAL NETWORK USED FOR HERE?

- A Back-Propagation Neural Network (BPNN) is used to identify all incoming new or unlearned events from the acceleration date downlinked from the International Space Station (ISS).

ISS Microgravity Environment Monitoring System (MEMS)

A THREE LAYERS NEURAL NETWORK ARCHITECTURE

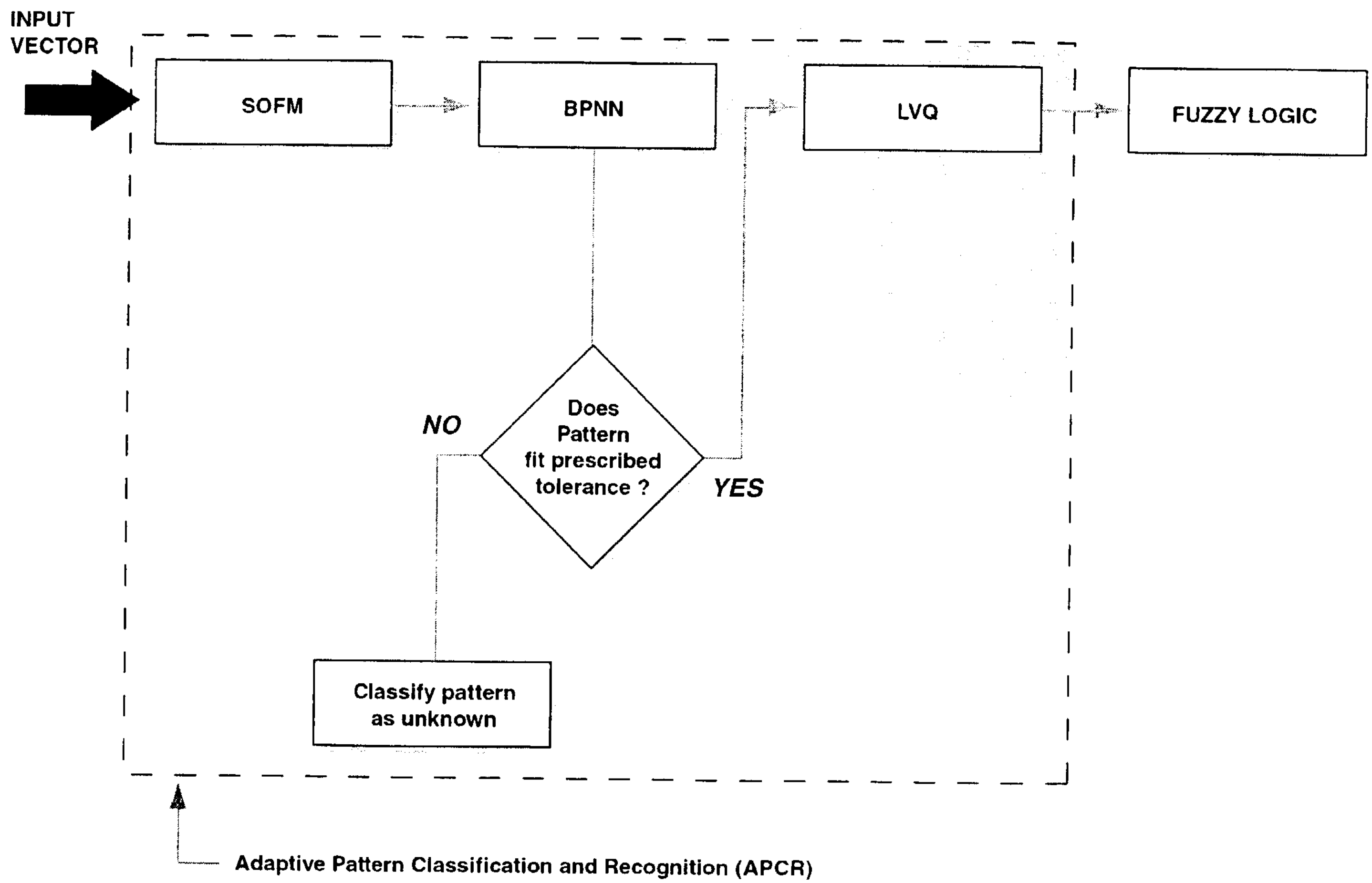


$a1 = F1(W1 * p + b1)$ $a2 = F2(W2 * a1 + b2)$ $a3 = F3(W3 * a2 + b3)$

$a3 = F3(W3 * F2(W2 * F1(W1 * p + b1) + b2) + b3)$

ISS Microgravity Environment Monitoring System (MEMS)

APCR & FUZZY LOGIC HYBRID ARCHITECTURE



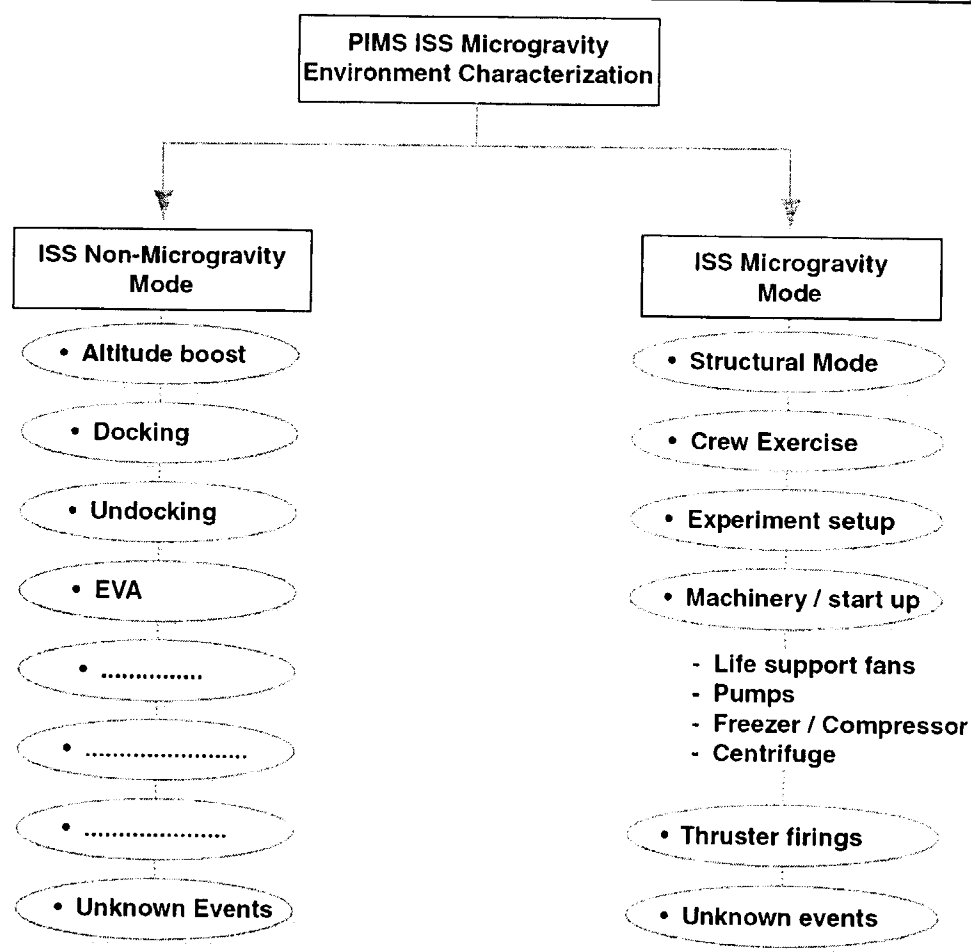
07/13/2000 NASA Gleen Research Center, Ohio 19th MGMG / Ohio / Page30

ISS Microgravity Environment Monitoring System (MEMS)

CONTENT

- Principal Investigator Microgravity Services (PIMS) -- Overview
- Problem Identification / Definition
- Proposed Solution
- Microgravity Environment Brief Description
- Soft Computing Techniques Description
- System Design Structure
- System Operative Modes
- Web-based Visual Display
- Discussion and Conclusion

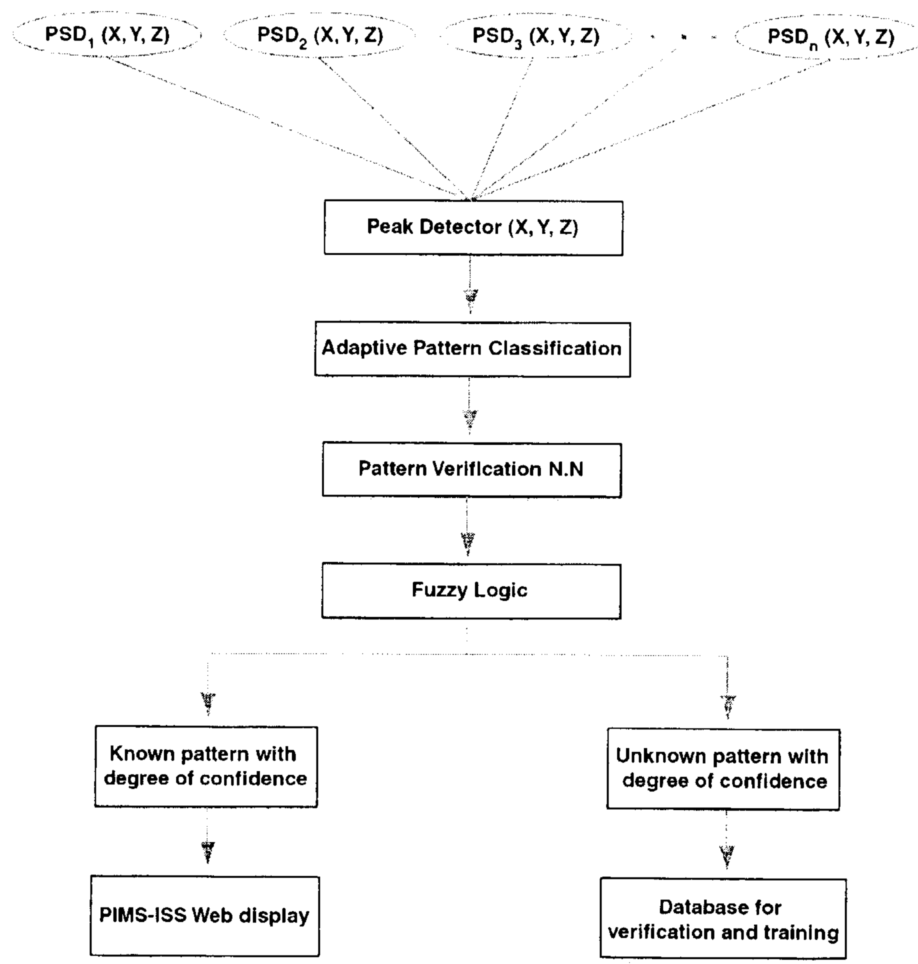
ISS Microgravity Environment Monitoring System (MEMS)



PIMS ISS-MEMS modes and events characterization

07/13/2000 NASA Gleen Research Center, Ohio 19th MGMG / Ohio / Page32

ISS Microgravity Environment Monitoring System (MEMS)

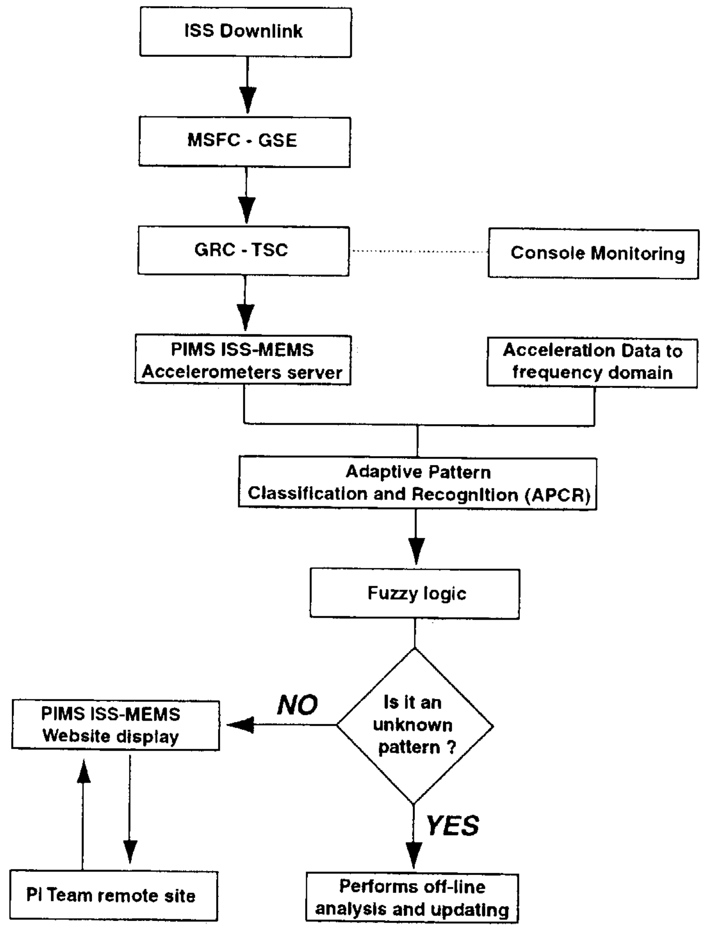


PIMS-ISS overall environment characterization

CONTENT

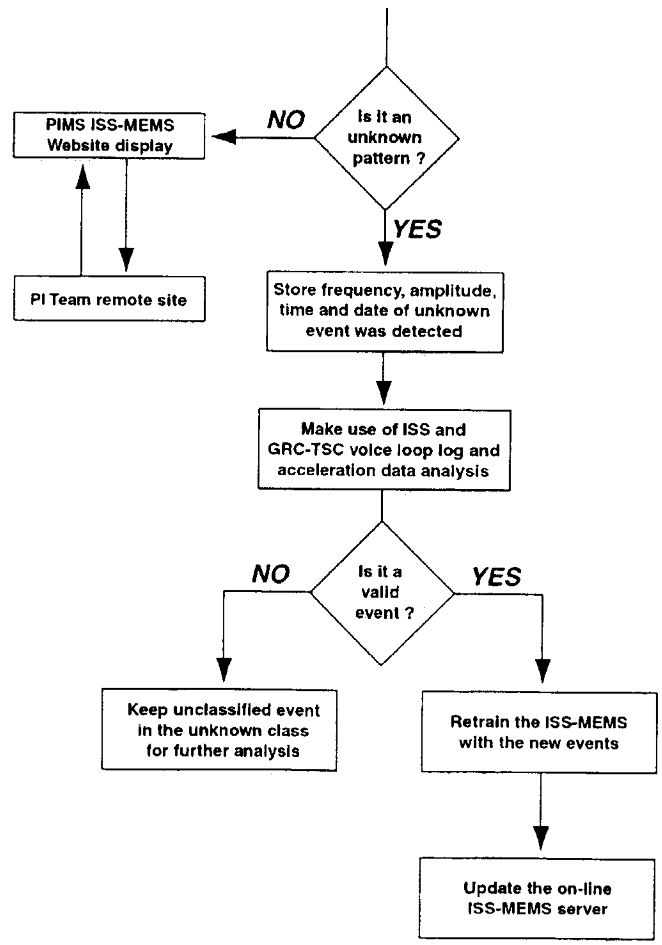
- Principal Investigator Microgravity Services (PIMS) -- Overview
- Problem Identification / Definition
- Proposed Solution
- Microgravity Environment Brief Description
- Soft Computing Techniques Description
- System Design Structure
- System Operative Modes
- Web-based Visual Display
- Discussion and Conclusion

ISS Microgravity Environment Monitoring System (MEMS)



PIMS ISS-MEMS on-line processing

ISS Microgravity Environment Monitoring System (MEMS)



PIMS ISS-MEMS off-line processing

07/13/2000 NASA Gleen Research Center, Ohio 19th MGMG / Ohio / Page36

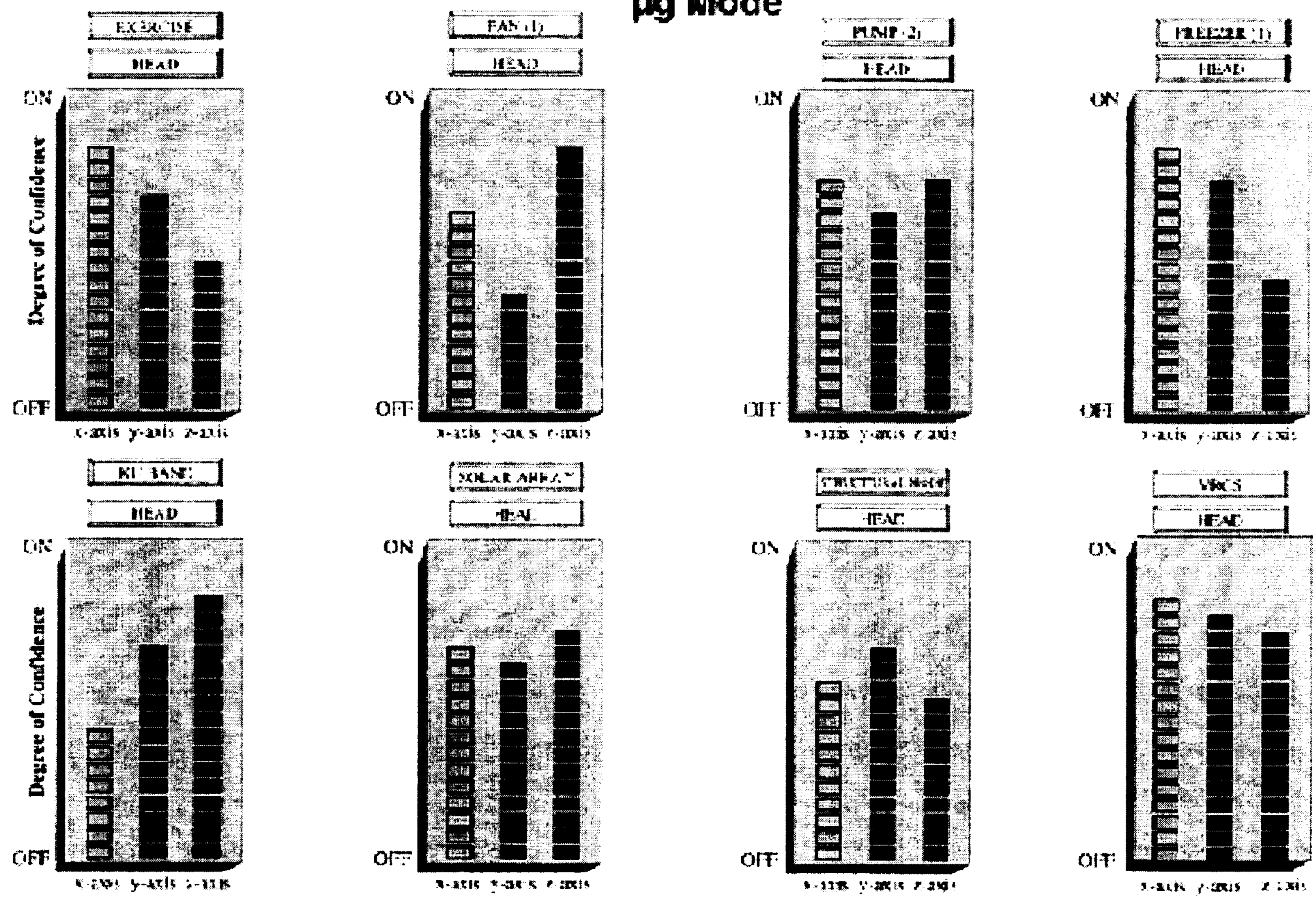
ISS Microgravity Environment Monitoring System (MEMS)

CONTENT

- Principal Investigator Microgravity Services (PIMS) -- Overview
- Problem Identification / Definition
- Proposed Solution
- Microgravity Environment Brief Description
- Soft Computing Techniques Description
- System Design Structure
- System Operative Modes
- Web-based Visual Display
- Discussion and Conclusion

ISS Microgravity Environment Monitoring System (MEMS)

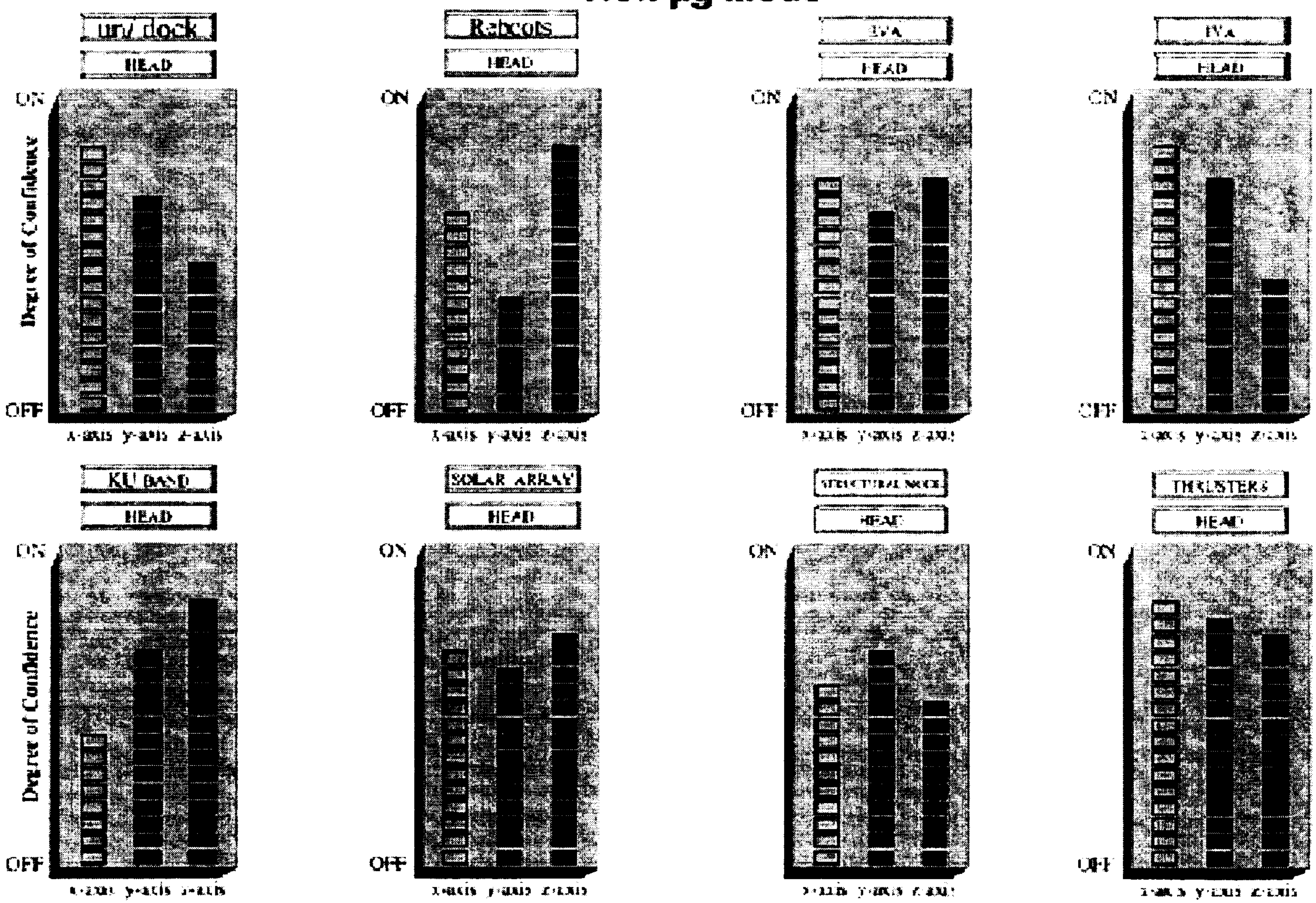
μg Mode



07/13/2000 NASA Glenn Research Center, Ohio 19th MGMG / Ohio / Page38

ISS Microgravity Environment Monitoring System (MEMS)

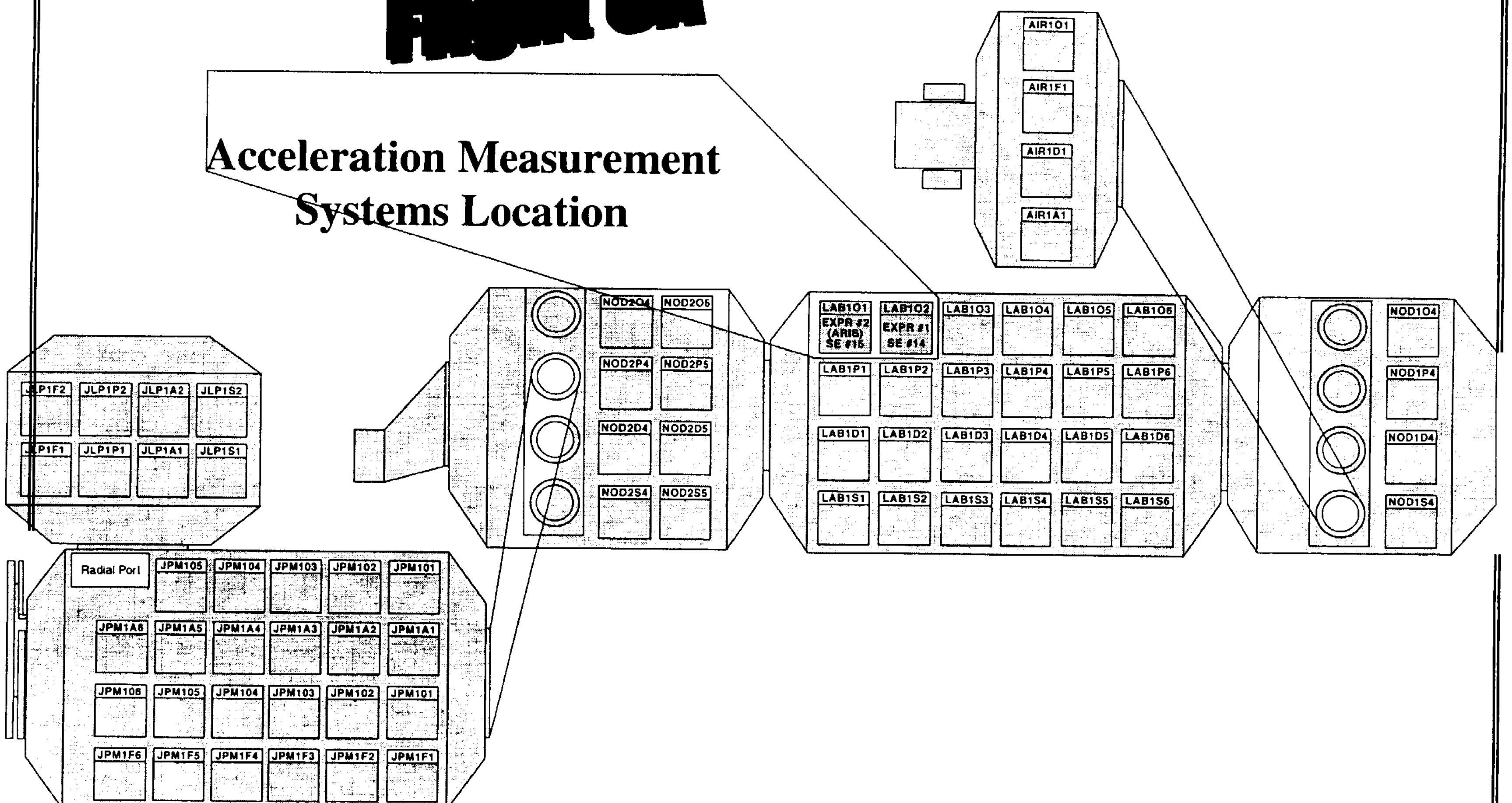
Non μg Mode



07/13/2000 NASA Glenn Research Center, Ohio 19th MGMG / Ohio / Page39

ISS Microgravity Environment Monitoring System (MEMS)

International Space Station Flight 6A



07/13/2000 NASA Glenn Research Center, Ohio 19th MGMG / Ohio / Page40

ISS Microgravity Environment Monitoring System (MEMS)

Event Log

Sensor Head : id

Axis : Z

Date : MM/DD/YY

Event Name : EXERCISE

Event Starting Time (GMT) : *YYYY:DDD:HH:MM:SS*

Event Ending Time (GMT): *YYYY:DDD:HH:MM:SS*

Event g-level $/_{av}$: ________

Event Frequency $/_{av}$: ________

Time Event Reaches Maximum Amplitude : ________

Maximum Amplitude : ________

07/13/2000 NASA Gleen Research Center, Ohio 19th MGMG / Ohio / Page41

ISS Microgravity Environment Monitoring System (MEMS)

CONTENT

- Principal Investigator Microgravity Services (PIMS) -- Overview
- Problem Identification / Definition
- Proposed Solution
- Microgravity Environment Brief Description
- Soft Computing Techniques Description
- System Design Structure
- System Operative Modes
- Web-based Visual Display
- Discussion and Conclusion

ISS Microgravity Environment Monitoring System (MEMS)

DISCUSSION & CONCLUSION

An artificial intelligence microgravity environment monitoring system design structure was presented. The system makes use of three artificial neural networks based techniques and fuzzy logic to accomplish the task of classifying and identifying all learned and unlearned events from the acceleration data that are downlinked from the International Space Station (ISS), in near real time.

"*Nihil simul inventum est et perfectum*"

The main drawback of this system, as it is the case with any dynamic system, is the lag time between when an event becomes active on-board the ISS and when the system actually detects the said event.

CHALLENGE:

The challenge for future work is how the lag time can be best minimized so that the system prediction can become truly "real time".

2000 1 2 2 512-70 527/29 1175

MGMG #19

Paper Number: 27

A method of simulation of microacceleration field from vibration source in microgravitational space platform

Valentin F. Agarkov
Central Specialized Design Bureau
Samara, Russia

K. B. Peresypkin
Central Specialized Design Bureau
Samara, Russia

B. D. Kozlov
Central Specialized Design Bureau
Samara, Russia

Description of a method of numerical modeling of microaccelerational levels propagating on the structure of a microgravitational platform from the sources of vibration in the levels from 0 to 300 Hz. Methods of finite elements are used to reduce the model of spacecraft.

The results of research are numerical values of frequency-amplitude characteristics between the platform structure and equipment mounted on the structure of the platform. These values are used to calculate microgravity levels in any given point.

V. F. Agarkov, K.V. Peresypkin, V.D. Kozlov

A Method of Simulation of Microacceleration Field from Vibration Source in Microgravitational Space Platform

Purpose

While designing a microgravitational platform it is advisable to have a method of estimation of on-board microacceleration. However current microacceleration estimation methods ignore spacecraft structural elastic motions. Determination of microaccelerations on the basis of physical experiments has some drawbacks. An engineer gets microacceleration data when spacecraft (SC) has already been manufactured or even launched. Not all structural motion parameters and not in all points of construction can be measured within physical experiment. Thus, development of a microacceleration estimation method presents interest for microgravitational platform design. This paper offers a method of research of on-board hardware (fans, pumps etc) excitation on microacceleration level in any point of a structure. Further the proposed method is applied to the available structure, that is «Foton» SC. In estimation we received an amplitude-frequency characteristic of acceleration in the structural point of interest (scientific hardware module attachment point) from excitation in the location of one of the vibration sources. This amplitude-frequency characteristic (AFC) is made for frequency range between 0 and 100 Hz and for different structural damping levels.

Microacceleration Estimation Method

The following microacceleration calculation algorithm is proposed.

- AFCs W_i of acceleration in the point under consideration from excitation in the location of the vibration sources under consideration (i is a vibration source number) are made using finite element method.
- AFCs are multiplied by excitation spectrum of respective vibration source S_i, and then obtained products are integrated by frequency f. The result of integrating is maximal acceleration (a sum of amplitudes of all harmonics), caused by each separate vibration source:

$$a_i^{\max} = \int_f W_i(f) \cdot S_i(f) df$$

– Summing up contributions from separate vibration sources, we find the maximal acceleration value in the point of interest:

$$a^{max} = \sum_i a_i^{max} .$$

For calculation AFCs the finite element method was selected because today it is the most developed simulation method of dynamic behavior of structure considering elasticity.

I'd like to touch upon some questions of finding AFCs W_i.

While finding AFCs, we ignore transients (activation of mechanisms, shocks etc). That is we consider forces, with which on-board hardware acts on the structure, vary with time in a harmonic manner with constant amplitude.

To consider excitation from on-board hardware it is necessary to study SC structure motion in the frequency range between 0 and 300 Hz. Research of structure vibration in such a wide frequency range requires a detailed structural simulation. It entails increase in the number of the unknown. In a dynamic analysis of problems with a large number of the unknown values it is logical to use a reduction method. Modal reduction method is used in this paper.

Calculation of AFC for descent module of «Foton 12» SC

In this example we consider only the descent module (DM) and not whole SC in view of the following considerations. Firstly, the structure of descent module/other SC compartment interface is characterized by a great damping and dampens vibrations considerably. Secondly, presumably, vibration sources, located near experimental facilities will produce the greatest effect on the acceleration values of experimental facilities. This presumption indicates that other conditions being equal, vibration sources inside DM will produce a greater effect on accelerations of these experimental facilities than other vibration sources.

The purpose of this estimation is finding a AFC of acceleration in one of IBIS attachment points on the lower frame from a gas-fluid unit excitation (See Fig. 1,2). For this purpose a harmonic force of 1 N amplitude is applied to gas-

fluid unit. Dependence of amplitude of response in the investigation point vs. excitation frequency will be the desired AFC. In this example AFC is found for frequency range between 0 and 100 Hz.

The estimation was made on MSC/NASTRAN finite element system. The finite element model has 32,034 unknown values and is shown in Fig. 1-4.

The modal reduction of this model was based on natural modes within frequency range from 0 to 300 Hz. This range has 127 natural frequencies. It should be mentioned that the majority of the obtained modes are of local character, that is only one of structural DM elements (hardware units, upper or lower frame or parachute container) oscillates essentially. There are no noticeable displacements of DM shell in the majority of modes. It indicates that DM shell is much more rigid than other structural elements. The rigid shell of DM isolates vibrations of frames and parachute container. The first modes of oscillation of some DM elements are shown at figures 5,6 and 7.

At present damping characteristics of the structure under consideration are not known. However in order to consider damping effect on maximal acceleration value in the point under consideration AFC was calculated for several damping levels. DM structure damping was assigned as modal damping. Modal damping factors for all modes are taken equal to each other. Five AFCs are calculated for modal damping factors, corresponding to logarithmic decrements, given in Table 1.

The obtained AFCs for modal damping levels under consideration are given in Fig. 8.

Table 1. Damping levels, for which AFC was calculated

N	Logarithmic decrement, δ	Percent of free vibration amplitude decrease per one vibration period
1	0,0	0%
2	0,0513	5%
3	0,1054	10%
4	0,2231	20%
5	0,3567	30%

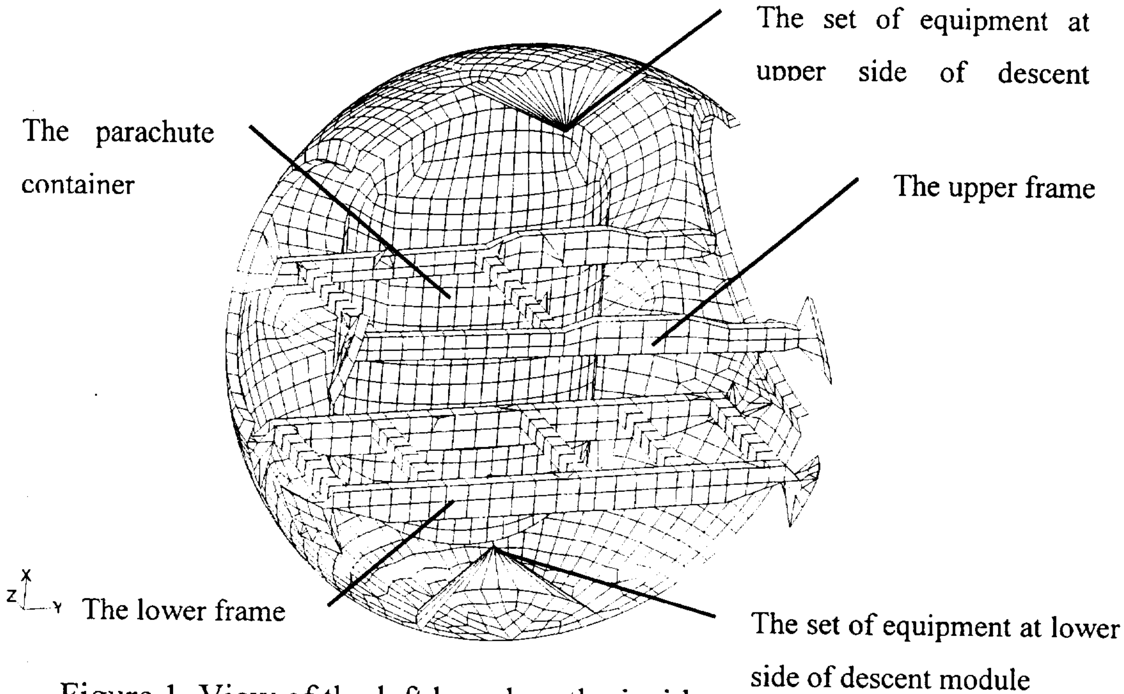


Figure 1. View of the left board on the inside

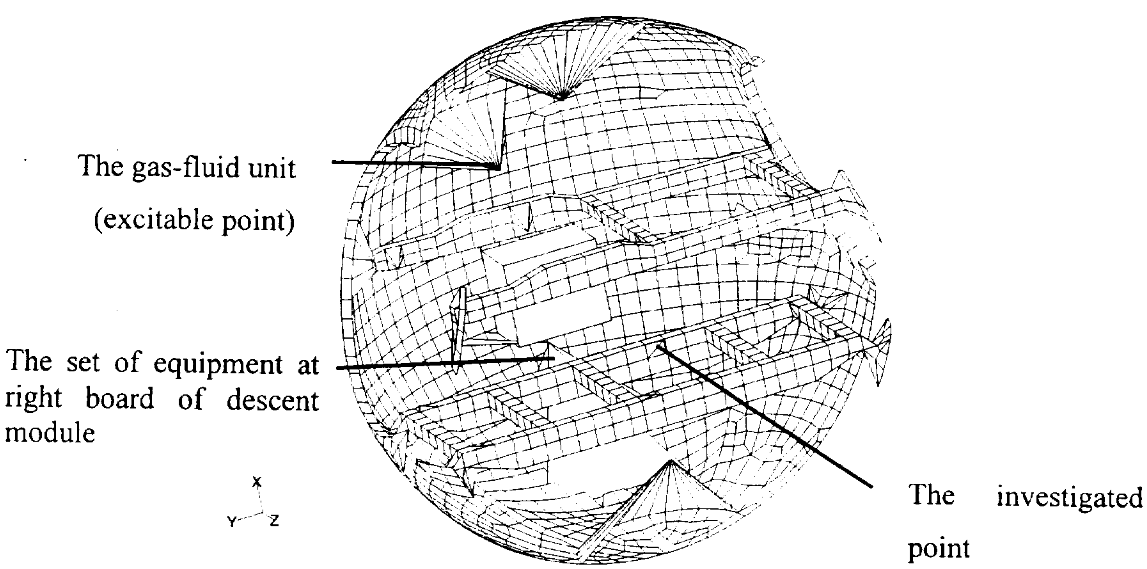


Figure 2. View of the right board on the inside

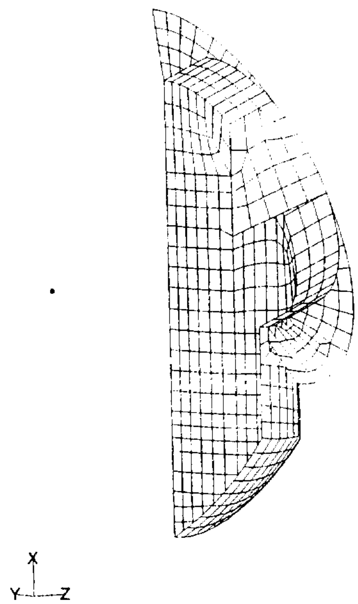


Figure 3. The parachute container

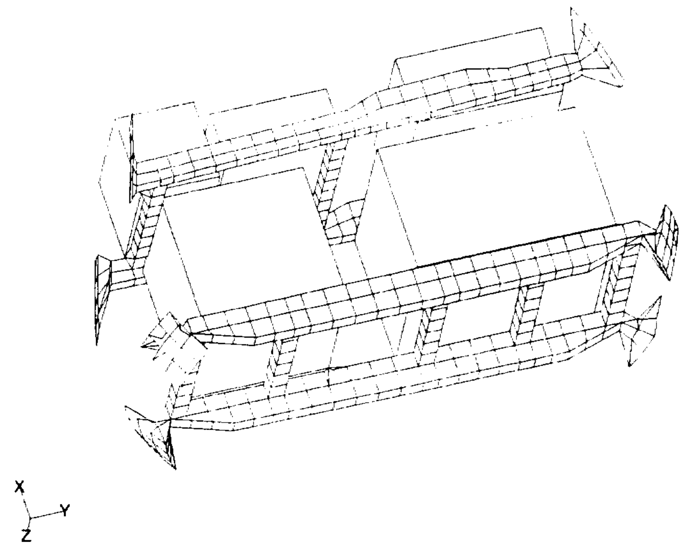


Figure 4. The set of equipment at the upper frame and the set of equipment at the lower frame

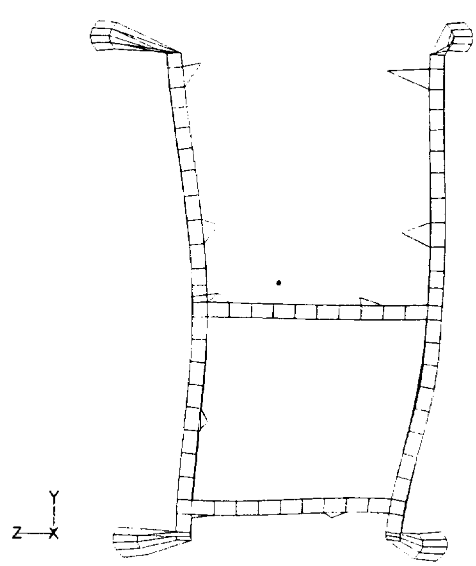


Figure 5. The first mode of the upper frame (36,5 Hz)

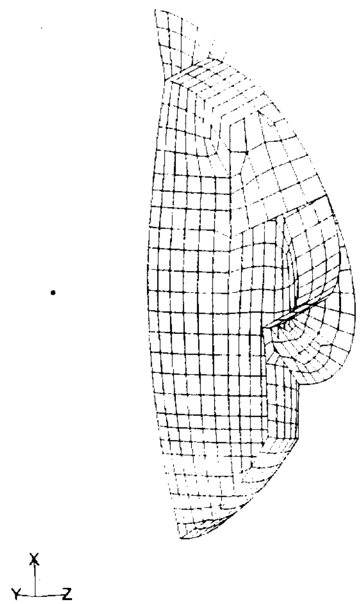


Figure 6. The first mode of the parachute container (63,8 Hz)

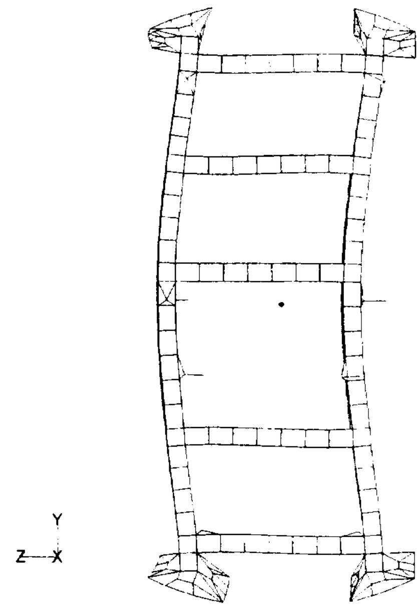


Figure 7. The first mode of the upper frame (66,5 Hz)

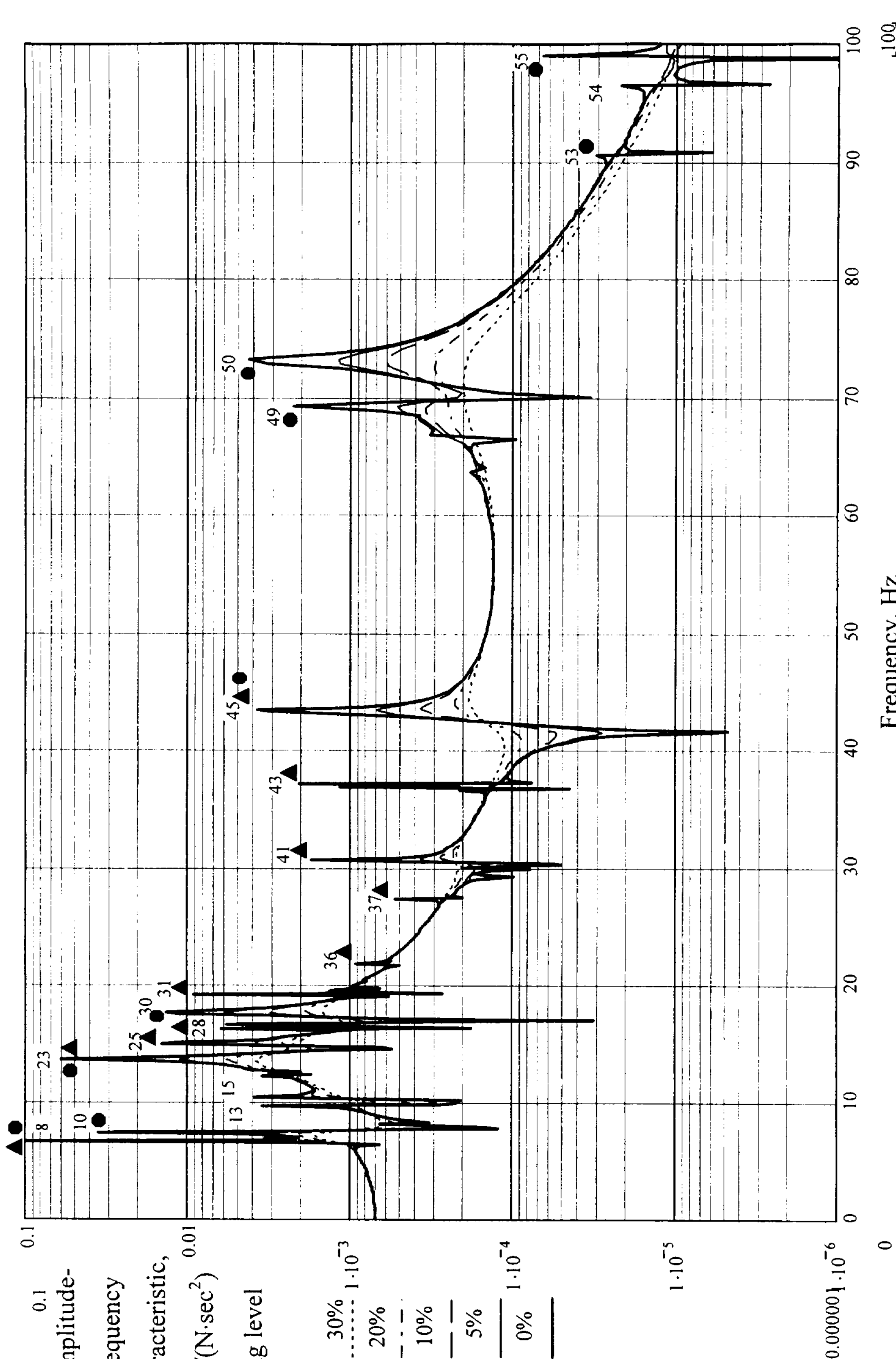


Figure 8. The amplitude-frequency characteristic for different levels of modal damping

Discussion of the obtained AFC

For the beginning let's consider AFC, received ignoring damping. When there is no damping, amplitude should increase to infinity at each natural frequency of structure vibration. As AFC was constructed on the basis of finite number of points, increase in amplitude at resonance frequencies (further the increase will be called resonance peak) is observed only to finite values. For the same reason the AFC under consideration has resonance peaks at far from all natural frequencies. Within 0 to 100 Hz frequency range there are 55 natural frequencies, only 27 peaks (ordinal numbers of natural frequencies are indicated in Fig. 8 near appropriate peak) can be marked at the AFC under consideration. The fact, that some peaks have not revealed themselves at AFC, shows that acceleration amplitudes of the vibration by respect modes are negligible except for a very narrow range around resonance frequency. As even with a small damping these peaks will fully disappear, we consider their discussion superfluous.

Let's discuss which modes the most revealed resonance peaks correspond to and why. Contribution of structure vibration by i-mode into j-point vibration amplitude is determined by multiplying j-component of i-eigenvector by amplitude with which i-mode participates in the vibrations of structure.

That is for modes, corresponding to an explicit peak at a AFC, must be either strongly excited under considered load or comprise great displacement in the investigated degree of freedom of structure concerning displacements in other degrees of freedom. Vibration modes with great displacement in excited degree of freedom concerning displacements in other degrees of freedom are strongly excited. Peaks, corresponding to modes with great displacement in the investigated point are marked with circles in Fig. 8. Peaks, corresponding to modes with great displacement in the excited point are marked with triangles in Fig. 8.

Two kinds of peaks can be singled out at AFC:

- peaks with a slanting slope from the one side and an abrupt one from another side (for example, peaks 13, 41, 53);

– peaks with two slanting slopes (for example, peaks 23, 45, 50).

The first kind of peaks can be explained by a known effect of vibration phase change for the opposite one during transition via resonance. That is acceleration amplitude of motion by the mode, corresponding to resonance frequency, on the one side of resonance is summed up with the total acceleration amplitude of motion by other modes, and on the other side of resonance, it is subtracted from the total acceleration amplitude of motion by other modes.

The second kind of peaks results from the fact that acceleration amplitude of motion by the mode, corresponding to the resonance frequency, is far greater than acceleration amplitude of motions by other modes. Therefore total amplitude with one of the sides becomes negative (with consideration of the phase) far off resonance frequency. While constructing the AFC under consideration, the phase is neglected and total point vibration amplitude is take into consideration by an absolute value. For this reason both slopes of such peaks are slanting.

Essentially, both kinds of peaks are of the same nature and differ only in contributions into structure motion. In most cases structural vibration by the mode, corresponding to the second kind of peak, makes an essential contribution to structural motion even far off resonance frequency of this mode. Structural vibration by the mode, corresponding to the first kind of peak, produces an essential effect on general structural vibrations only in the vicinity of the resonance frequency.

Some words on damping effect. As shown in Fig. 8, peak height decreases with damping increase and results in decrease of resonance condition contribution into acceleration amplitude. Far from resonance acceleration amplitude value has a small dependence on damping. This result is not something unexpected.

Some words about possible practical application of such AFC to decrease accelerations of the given point. Supposing, gas-fluid unit affects structure with a frequency of ~70 Hz. Fig. 8 shows that in the vicinity of 70 Hz AFC has a group of peaks, which will produce an unfavorable effect on acceleration level in the point,

which the given AFC is constructed for. It should be noted that this group of peaks corresponds to modes of the lower frame vibrations. In this case, an engineer can raise stiffness of units of hardware attachment to the lower frame. This measure will increase inertial properties of the lower frame during vibration with frequencies near 70 Hz. As a result of this, a group of peaks, located in the vicinity of 70 Hz will shift to lower frequencies and excitation will be related not to this group of peaks but to a relatively low part of AFC that occupied frequencies between 70 Hz and 90 Hz before modification. Thus, in this specific case we can decrease acceleration level in hardware attachment point without changing gas-fluid unit or its location.

OMIT TO END

Attendee List

Agarkov, Valentin F.
Central Specialized Design Bureau
18A ul.Pskovskaya
Samara, 443009, Russia
Phone: (846-2) 92-65-31
Fax: (846-2) 92-65-18
e-mail is unavailable

Beatty, Richard G.
Program Engineer, Microgravity
Fundamental Physics
Jet Propulsion Laboratory 233-200
4800 Oak Grove Drive
Pasadena, CA 91109
Phone: 818-393-1923
Fax: 818-393-5273
richard.beatty@jpl.nasa.gov

Bushnell, Glenn
The Boeing Corporation
Mail Stop 82-24
20403 - 68th Ave. South
Kent WA 98032
Phone: 206-773-7677
Fax: 206-773-2250
glenn.bushnell@pss.boeing.com

Christoffersen, Roy
ISS Payloads Office
SAIC
2200 Space Park Drive, Suite 200
Houston, TX 77058
Phone: 281-244-8380
Fax: 281-244-8292
roy.christoffersen1@jsc.nasa.gov

Clancy, Jeff
MSRR-1
Pace & Waite, Inc.
NASA MSFC SD42
MSFC, AL 35812
Phone: 256-544-3572
Fax: 256-544-5892
jeffrey.clancy@msfc.nasa.gov

Crenwelge, Otto
DYNACS Inc. / Boeing
M/S ZC-01
502 Gemini
Houston, TX 77058
Phone: 281-853-1602
Fax: 281-853-1523
otto.crenwelge@sw.boeing.com

Del Basso, Steve
The Boeing Company
502 Gemini Ave
M/S: 831-ZC01
Houston, TX 77058
Phone: 281-853-1603
Fax: 281-853-1524
steve.delbasso@sw.boeing.com

DeLombard, Richard
Acceleration Measurement Disc. Scientist
NASA GRC
M/S 500-216
21000 Brookpark Road
Cleveland, OH 44135
Phone: 216-433-5285
Fax: 216-433-8660
richard.delombard@grc.nasa.gov

Denniston, Charles
FCF Project
NASA GRC
M/S: 86-10
21000 Brookpark Road
Cleveland, OH 44135
Phone: 216-433-8534
Fax: 216-433-6382
Charles.Denniston@grc.nasa.gov

Duval, Walter
NASA GRC
M/S 105-1
21000 Brookpark Road
Cleveland, OH 44135
Phone: 216-433-5023
Fax: 216-433-5033
walter.m.duval@grc.nasa.gov

Fialho, Ian J.
International Space Station
The Boeing Corporation
MS - HS44
2100 Space Park Drive
Houston, TX 77058
Phone: 281-336-5021
Fax: 281-336-5341
ian.fialho@sw.boeing.com

Fortier, Rejean
Canadian Space Agency
6767, route de l'Aeroport
Saint Hubert, Quebec
Canada J3Y 8Y9
Phone: 450-926-4548
Fax: 450-926-4579
Rejean.Fortier@space.gc.ca

Foster, William M. II
SAMS Project Manager
NASA GRC
M/S 500-102
21000 Brookpark Rd.
Cleveland, OH 44135
Phone: 216-433-2368
Fax: 216-433-8660
W.M.Foster@grc.nasa.gov

Fox, James C.
Canopus Systems Inc.
P.O. Box 130319
Ann Arbor, MI 48113-0319
Phone: 734-971-4422
Fax: 734-971-5243
fox@canopus.com

Francisco, David
Acceleration Measurement Program Manager
NASA GRC
M/S 500-216
21000 Brookpark Rd.
Cleveland, OH 44135
Phone: 216-433-2653
Fax: 216-433-8660
David.R.Francisco@grc.nasa.gov

Ganesan, Naga
Lockheed Martin
2400 NASA Road 1
Houston, TX 77058
Phone: 281-333-6928
naga.ganesan@lmco.com

Goodnight, Thomas
Structural Systems Dynamics Branch
NASA GRC
M/S 86-10
21000 Brookpark Rd.
Cleveland, OH 44135
Phone: 216-433-2381
Fax: 216-433-6382
Thomas.W.Goodnight@grc.nasa.gov

Grodsinsky, Carlos
Zin Technologies
3000 Aerospace Parkway
Brook Park, OH 44152
Phone: 216-977-0316
Fax: 216-977-0350
grodsinskyc@mail.zin-tech.com

Henderson, Frederick H.
Boeing/Teledyne Brown Engineering
2100 Space Park Drive, HS-44
Nassau Bay, TX 77058
Phone: 281-336-4256
Fax: 281-336-5341
Fred.Henderson@SW.Boeing.com

Houston, Janice
Sverdrup Technology, Inc.
620 Discovery Drive
Huntsville, AL 35806
Phone: 256-971-9422
Fax: 256-971-9475
Janice.Houston@hsv.sverdrup.com

Hrovat, Kenneth
Zin Technologies
NASA GRC
M/S 500-216
21000 Brookpark Road
Cleveland, OH 44135
Phone: 216-433-3564
Fax: 216-433-8660
Kenneth.Hrovat@grc.nasa.gov

Ikeda, Toshitami
NASDA
Tsukuba Space Center
2-1-1 Sengen
Tsukuba-city, Ibaraki 305-8505
Japan
Phone: +81-298-52-2778
Fax: +81-298-50-2233
ikeda.toshitami@nasda.go.jp

Jules, Kenol
NASA GRC
M/S 500-216
21000 Brookpark Rd.
Cleveland, OH 44135
Phone: 216-977-7016
Fax: 216-433-8660
kenol.jules@grc.nasa.gov

Kacpura, Thomas
ZIN Technologies
3000 Aerospace Parkway
Brook Park, OH 44142
Phone: 216-977-0420
Fax: 216-977-0350
Thomas.Kacpura@grc.nasa.gov

Kelly, Eric M.
Zin Technologies
NASA GRC
M/S 500-216
21000 Brookpark Road
Cleveland, OH 44135
Phone: 216-433-5162
Fax: 216-433-8660
Eric.M.Kelly@grc.nasa.gov

Knabe, Walter
DySAT
Am Eversberg 6
D-27308 Kirchlinteln
Germany
Phone: +49-4231-63815
Fax: +49-4231-931250
e-mail is unavailable

Knight, Brent
ISS EXPRESS Rack
Teledyne Brown Engineering
Mail Stop 167
P.O. Box 070007
Huntsville, AL 35807-7007
Phone: 256-961-1450
Fax: 256-544-4966
brent.knight@tbe.com

Lekan, Jack
NASA GRC
M/S 500-216
21000 Brookpark Road
Cleveland, OH 44135
Phone: 216 433-3459
Fax: 216 433-8660
Jack.Lekan@grc.nasa.gov

Liberman, Gene
PIMS Project
NASA GRC
M/S 500-216
21000 Brookpark Road
Cleveland, OH 44135
Phone: 216 433-8518
Fax: 216 433-8660
Eugene.M.Liberman@grc.nasa.gov

Mallinak, Lynn
InDyne, Inc.
NASA GRC
M/S 500-216
21000 Brookpark Road
Cleveland, OH 44135
Phone: 216-433-2637
Fax: 216-433-8660
Lynn.Mallinak@grc.nasa.gov

McNelis, Anne M.
Structural Systems Dynamics Branch
NASA GRC
M/S 86-10
21000 Brookpark Rd.
Cleveland, OH 44135
Phone: 216-433-8880
Fax: 216-433-6382
Anne.M.McNelis@grc.nasa.gov

McNelis, Mark E.
NASA GRC
M/S 86-10
21000 Brookpark Road
Cleveland, OH 44135
Phone: 216-433-8395
Fax: 216-433-8000
Mark.E.McNelis@grc.nasa.gov

Monti, Rodolfo
Dept. of Space Science & Engineering
University of Naples
Piazzale V. Tecchio, 80
80125 Naples - Italy
Phone: +39 081 7682359
Fax: +39 081 5932044
monti@unina.it

Mortensen, Dale
Zin Technology
3000 Aerospace Parkway
Brook Park, OH 44142
Phone: 216-977-0348
Fax: 216-977-0350
dale.mortensen@grc.nasa.gov

Nelson, Emily S.
NASA GRC
M/S 105-1
21000 Brookpark Rd.
Cleveland, OH 44135
Phone: 216-433-3468
Fax: 216-433-5033
Emily.S.Nelson@lerc.nasa.gov

Perkins, Brad
NASA MSFC SD41
MSFC, AL 35812
Phone: 216-544-1357
Fax: 256-544-3554
Brad.Perkins@msfc.nasa.gov

Richter, Hans-Ewald
DLR, Institute for Space Simulation
Linder Hohe
51147 Koln
Germany
Phone: 0049 / 2203-6012170
Fax: 0049 / 2203-61768
EWALD.RICHTER@DLR.DE

Rogers, Melissa
NCMR at NASA GRC
M/S 110-3
21000 Brookpark Rd.
Cleveland, OH 44135
Phone: 216-433-2332
Fax: 216-433-3793
Melissa.J.Rogers@lerc.nasa.gov

Samorezov, Sergey
Zin Technologies
NASA GRC
M/S Zin
21000 Brookpark Road
Cleveland OH 44135
Phone: 216-977-0354
Fax: 216-977-0350
Sergey.Samorezov@grc.nasa.gov

Tryggvason, Bjarni
Canadian Space Agency
Mail Code CB
Johnson Space Center
2101 NASA Road 1
Houston, TX, 77058-3696
Phone: 281-244-2621
Fax: 281-244-7279
Btryggva@jsc.nasa.gov

Ward, Professor Charles A.
Dept. of Mechanical & Industrial Engineering
University of Toronto
5 King's College Road
Toronto, Canada M5S 3G8
Phone: 416-978-4807
Fax: 416-978-7322
ward@mie.utoronto.ca

Weiland, Karen J.
NASA GRC
M/S 110-3
21000 Brookpark Road
Cleveland, OH 44135
Phone: 216-433-3263
Fax: 216-433-3793
Karen.Weiland@grc.nasa.gov

Weiss, Daniel
NASA GRC
M/S 500-216
21000 Brookpark Road
Cleveland, OH 44135
Phone:
Fax: 216-433-8660
Karen.Weiland@grc.nasa.gov

Whorton, Mark
TD55/Vehicle Control Systems
NASA MSFC
MSFC, AL 35812
Phone: 256-544-1435
Fax: 256-544-5416
mark.whorton@msfc.nasa.gov

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (*Leave blank*)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	October 2000	Conference Publication

4. TITLE AND SUBTITLE

Nineteenth International Microgravity Measurements Group Meeting

5. FUNDING NUMBERS

WU–398–95–0G–00

6. AUTHOR(S)

Richard DeLombard, compiler

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

National Aeronautics and Space Administration
John H. Glenn Research Center at Lewis Field
Cleveland, Ohio 44135–3191

8. PERFORMING ORGANIZATION REPORT NUMBER

E–12428

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

National Aeronautics and Space Administration
Washington, DC 20546–0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

NASA CP—2000-210374

11. SUPPLEMENTARY NOTES

Abstracts and viewgraphs of a conference sponsored by the Microgravity Science Division, NASA Glenn Research Center and held at the Sheraton Airport Hotel, Cleveland, Ohio, July 11–13, 2000. Responsible person, Richard DeLombard, organization code 6727, (216) 433–5285.

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Unclassified - Unlimited
Subject Categories: 19, 18, and 35 Distribution: Nonstandard
Available electronically at http://gltrs.grc.nasa.gov/GLTRS
This publication is available from the NASA Center for AeroSpace Information, (301) 621–0390.

12b. DISTRIBUTION CODE

13. ABSTRACT ***(Maximum 200 words)***

The Microgravity Measurements Group meetings provide a forum for an exchange of information and ideas about various aspects of microgravity acceleration research in international microgravity research programs. These meetings are sponsored by the PI Microgravity Services (PIMS) project at the NASA Glenn Research Center. The 19th MGMG meeting was held 11–13 July 2000 at the Sheraton Airport Hotel in Cleveland, Ohio. The 44 attendees represented NASA, other space agencies, universities, and commercial companies; 8 of the attendees were international representatives from Japan, Italy, Canada, Russia, and Germany. Twenty-seven presentations were made on a variety of microgravity environment topics including the International Space Station (ISS), acceleration measurement and analysis results, science effects from microgravity accelerations, vibration isolation, free flyer satellites, ground testing, vehicle characterization, and microgravity outreach and education. The meeting participants also toured three microgravity-related facilities at the NASA Glenn Research Center. Contained within the minutes is the conference agenda, which indicates each speaker, the title of their presentation, and the actual time of their presentation. The minutes also include the charts for each presentation, which indicate the authors' name(s) and affiliation. In some cases, a separate written report was submitted and has been included here.

14. SUBJECT TERMS	15. NUMBER OF PAGES
Microgravity; Instrumentation; International Space Station	770
	16. PRICE CODE: A99

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	